A Longitudinal Study on Raynaud’s Phenomenon in Workers Using an Impact Wrench

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Abstract: A Longitudinal Study on Raynaud’s Phenomenon in Workers Using an Impact Wrench: Yoko Aiba, et al. Occupational Health Research and Development Center, Japan Industrial Safety and Health Association—Objectives: The purpose of this study was to clarify the occurrence of Raynaud’s phenomenon among workers using an impact wrench for a long time. Methods: The subjects were 704 workers regularly using an impact wrench and taking special medical examinations for vibration syndrome from 1981 to 2008. Raynaud’s phenomenon was observed in 39 subjects during the observation period. Results: The mean operating years at the occurrence of Raynaud’s phenomenon was 25.5 ± 8.3 (standard deviation) yr. The mean total operating time (geometric average) at the occurrence of Raynaud’s phenomenon was 11,689 h. By the person-year method, the incidence rate of Raynaud’s phenomenon was 6.27 persons per 1,000 person-years. The estimated risk of developing Raynaud’s phenomenon did not increase until 12 years after starting to operate an impact wrench but increased exponentially after that. The vibration level of an impact wrench (from 4.9 m/s² to 22.6 m/s²) exceeded the occupational exposure limit value (4.9 m/s²). Various countermeasures, such as introducing automatically apparatus and keeping the working environment warm to protect from cold exposure, were taken at the factory. Conclusions: These findings showed that the rate of occurrence of Raynaud’s phenomenon was high, although the vibration level of the impact wrench was high. This may result from various countermeasures to prevent the occurrence of Raynaud’s phenomenon. A long period of exposure to vibration had the potential to lead to the occurrence of Raynaud’s phenomenon even under various countermeasures. (J Occup Health 2012; 54: 96–102)

Key words: Countermeasure, Frequency-weighted vibration acceleration, Hand-arm vibration syndrome, Impact wrench, Person-year method, Raynaud’s phenomenon

Occupational exposure to vibration by hand-held vibrating tools causes vibration syndrome. The most prominent hand-arm vibration syndrome is Raynaud’s phenomenon¹. Many cross-sectional and longitudinal investigations on vibration syndrome among workers using vibrating tools have been reported, and a dose-response relationship has been established between exposure to vibration and the occurrence of Raynaud’s phenomenon on the basis of epidemiological studies²–⁶. Recently, technical improvements have been made to vibrating tools to decrease their vibration levels⁷–¹⁰. A decrease in the occurrence of Raynaud’s phenomenon has already been noted in recent years¹¹.

The vibration level of the impact wrench is high compared with other hand-held vibrating tools¹². However, few studies¹³ have reported the occurrence of Raynaud’s phenomenon for workers using an impact wrench in longitudinal studies. Our previous study¹⁴ reported that various countermeasures taken on several occasions for workers using an impact wrench were effective in decreasing symptoms and prevalence of abnormal findings in special medical examinations for vibration syndrome at a factory. Furthermore, our previous study¹⁵ showed results in which a decrease in Raynaud’s phenomenon was due to the combined effect of introducing a vibration-proof impact wrench.
and taking countermeasures against cold working environments. We next assumed that even if working environmental measures has been taken, exposure to the vibrations of an impact wrench for a long time would result in the occurrence of Raynaud’s phenomenon.

In this study, a longitudinal study was undertaken to clarify the occurrence of Raynaud’s phenomenon in workers using an impact wrench for a long time, although various countermeasures for Raynaud’s phenomenon in workers were taken for a period of 27 yr.

Subjects and Methods

Special medical examinations for vibration syndrome

The workers used an impact wrench to screw in or unscrew bolts in the processes of molding and unmolding at a factory manufacturing concrete electric light poles. Special medical examinations for vibration syndrome began at the factory in 1981. They consisted of a primary medical examination and a secondary medical examination (Japanese Labour Standards Bureau Notification, No. 609)\(^{(a)}\). Each subject was asked to complete a questionnaire regarding their work history, medical history and subjective symptoms, including Raynaud’s phenomenon. All subjects using a vibrating tool were scheduled to take a special medical examination for vibration syndrome every year. However, some of them did not take a special medical examination in a year.

Figure 1 shows the number of examinees per year for 1981–2008. The total number of workers using vibrating tools was 271 persons in 1981. The number of workers who took a special medical examination in 1981 was 173 persons. This shows that about 64% of workers took a special medical examination in that year. The number of examinees was especially low in 1986. This was because those who had no abnormal findings in the last examination were not required to take a special medical examination. As the total number of employees at the factory gradually decreased, the number of subjects who took a special medical examination decreased from 1995.

Subjects

The subjects in this study were 704 (685 male and 19 female) workers who took special medical examinations each winter for 27 yr from 1981 to 2008. The ages of the subjects at the first special medical examination ranged from 18 to 62 yr. The subjects in their forties were a majority (238 subjects), followed by those in their fifties (186 subjects) and those in their thirties (149 subjects). Seventy-eight subjects were in their twenties, and 51 subjects were in their teens. Two subjects were in their sixties. The mean age at the first special medical examination was 40.8 ± 11.4 (standard deviation) yr. Four hundred fifty-nine subjects (65.2%) had a smoking habit at the first special medical examination. The observation period of each subject began in the year when the subject took a special medical examination for the first time and ended in the year of the last special medical examination. The end of the observation period was considered to be 2008. The mean observation period was 10.6 ± 7.4 yr.

The protocol of this study was approved by the Ethics Committee of Wakayama Medical University.

Raynaud’s phenomenon

In this study, a subject who was identified as having Raynaud’s phenomenon in at least one finger on either hand or both hands was considered to be a worker with Raynaud’s phenomenon. To identify Raynaud’s phenomenon, a medical doctor asked the subjects in detail about the sites, frequency and factors related to Raynaud’s phenomenon and showed them a photograph of typical Raynaud’s phenomenon to confirm it. Judging from daily working conditions in addition to information from each questionnaire, the medical doctor diagnosed subjects as having Raynaud’s phenomenon due to vibration syndrome. Those who had Raynaud’s phenomenon and at the same time a past history of accident, injury of the fingers or hand and so on were diagnosed as having traumatic Raynaud’s phenomenon. Forty-two of the 704 examinees were identified as having Raynaud’s phenomenon. Three subjects with traumatic Raynaud’s phenomenon were excluded, so for this study, 39 workers were selected as subjects who had Raynaud’s phenomenon at least one time during the observation period.
Total operating time
In order to determine the vibration exposure dose for the subjects, total operating time (TOT) was used as the index at the time of occurrence of Raynaud’s phenomenon. TOT was calculated from the occupational history provided in the questionnaire using the following factors: operating hours per day, operating days per year and operating years.

Stages of Raynaud’s phenomenon
The stages of Raynaud’s phenomenon were classified by the Stockholm Workshop scale17. The subjects were evaluated using the highest stage of Raynaud’s phenomenon that they attained during the observation period.

Person-year method
The person-year method was used to estimate the incidence rate of Raynaud’s phenomenon in consideration of the number of subjects and their individual observation periods. In this method, one person-year is calculated for one person observed for one year during an observation period. This method is independent of the length of the individual observation period for each subject and enables us to effectively use the data for both long-term observed subjects and short-term observed subjects and to compare our results with those of the other group without considering the observation period.

In this study, some of the subjects had years in which they did not take a special medical examination. We regarded subjects who did not take a special medical examination in the year between two years in which they did take a special medical examination as having had a special medical examination and had no Raynaud’s phenomenon.

Estimated risk of developing Raynaud’s phenomenon
The association between the risk of developing Raynaud’s phenomenon and operating years was evaluated by estimation with the Kaplan-Meier survival curve. A Cox proportional hazard survival model was used to estimate hazard risk of gender, age at first operation and smoking habit at the first special medical examination in determining the estimated risk. The mean age at first operation was 33.8 ± 11.4 yr.

The null hypothesis was rejected at p<0.05 as the level of significance. Data analysis was performed using IBM SPSS Statistics, Version 19.

Frequency-weighted vibration acceleration
Measurements were conducted at five workplaces in the factory. On the investigation day, eight vibrating tools that subjects operated daily were selected from a total of two thousands tools. They were the typical tools that the workers used daily and often. The workers used the tools in a similar way to screw in or unscrew bolts throughout the whole day. At the different work sites, however, the workers used different tools for different jobs.

The vibration levels of tools were measured on the handle or switch side according to the type of tool while a subject was screwing in or unscrewing a bolt. The instruments used to measure the vibration level were a vibration pickup (triaxis piezoelectric type, 29.3 gr., PV-93T, RION Co., Ltd., Tokyo, Japan), a vibration meter (3 ch. VM-19A, RION Co., Ltd., Tokyo, Japan) and a data recorder (4 ch. DAT type, RD-120T, TEAC Corporation, Tokyo, Japan). The vibration pickup was mounted firmly with a pair of steel belts (6.4 mm wide × 0.5 mm thick) and a fitting base on a handle of the object tool (1 point or more measured per tool). These instruments were able to measure the vibration acceleration signals of three axes simultaneously.

The recorded data were analyzed with a one-third octave band real-time analyzer (SA-27, RION Co., Ltd., Tokyo, Japan). The frequency-weighted energy equivalent acceleration values (root mean square, rms) were obtained by the measuring instruments. The time to average the measured data varied from 30 sec to 90 sec depending on the type of tool and work conditions. Acceleration magnitudes of the tools were determined by the ISO 5349 method18. The total vibration value \( [a_{hv}] \) is a combined value of three orthogonal axes defined in the following equation.

\[
a_{hv} = \sqrt{a_{hwx}^2 + a_{hwy}^2 + a_{hwz}^2},
\]

where \( a_{hwx}, a_{hwy} \) and \( a_{hwz} \) are the frequency-weighted root-mean-squared acceleration magnitudes for the x, y and z axes.

Measurements of vibration levels were taken in 1994. This year had more examinees and was the middle year of the 1981–2008 study period.

Countermeasures
We asked health supervisors at the factory to show us records about a various countermeasures. We received a document on how to improve the tools or the working environment and when to carry out countermeasures.

Results
Table 1 shows the age distribution at the time of occurrence of Raynaud’s phenomenon in 39 subjects during the observation periods. Their ages ranged from 35 to 59 yr. The mean age was 49.2 ± 7.3 yr.

The distribution of operating years at the time of occurrence of Raynaud’s phenomenon is shown in Fig. 2. The operating years ranged from 7 to...
42 yr, and the mean was 25.5 ± 8.3 yr. The majority of operating years were between 20 and 24 yr (11 subjects). Two subjects showed exceptionally long operating years exceeding 40 yr. Each subject was also asked to complete a questionnaire on the amount of time per day and days per year they spent using an impact wrench. The subjects answered 2.6 ± 2.0 h per day and 216.0 ± 54.2 days per year on average.

Figure 3 shows the distribution of TOT at the time of occurrence of Raynaud’s phenomenon. Since the TOT showed a logarithmically normal distribution, we used the logarithmic axis as the horizontal axis. Eighteen of the 39 subjects showed a TOT between 10,240 h and 20,480 h. The mean TOT (geometric mean) at the time of occurrence of Raynaud’s phenomenon was 11,689 h.

On the Stockholm Workshop scale, 19 subjects were classified into Stage I, 19 subjects were classified into Stage II and one subject was classified into Stage III. No subject was found to have Stage IV.

The total observation person-years of the 704 workers was 6,215.5, and the incidence rate of Raynaud’s phenomenon in the 39 subjects was 6.27 persons per 1,000 person-years for the 27-year observation period.

The survival curve is shown in Fig. 4. The estimated risk of developing Raynaud’s phenomenon was around 0.002 to 0.004 for 7–12 operating years. It increased exponentially at more than 12 operation years. A Cox analysis found the three independent variables, gender, age at first operation and smoking habit at the first special medical examination, to be not significantly associated with the estimated risk of developing Raynaud’s phenomenon.

The frequency-weighted vibration accelerations of 15 pickup points of the 8 measured tools were recalculated and are summarized in Table 2. The frequency-weighted vibration acceleration of tools varied between 4.9 m/s² and 22.6 m/s². The values of 14 of the 15 pickup points were higher than the occupational exposure limit value (4.9 m/s²)¹⁹ for 2.6 h.
According to the EU Directive (2002/44/EC)\textsuperscript{20}, A (8) was defined as a frequency-weighted acceleration of 8 hours per day. An exposure action value of 2.5 m/s\textsuperscript{2} and an exposure limit value of 5.0 m/s\textsuperscript{2} are recommended for assessment of the value of A (8). A (8) is computed in the following equation.

\[ A (8) = a_{hw} \times \sqrt{T/8}, \]

where \( a_{hw} \) is the frequency-weighted acceleration sum, and \( T \) is the time.

All the values of A (8) for the 15 pickup points (Table 2) were over the exposure action value (2.5 m/s\textsuperscript{2}), and the values of 9 of the 15 pickup points were higher than exposure limit value (5.0 m/s\textsuperscript{2}).

Various countermeasures for workers using an impact wrench were taken from 1973 to 2005 at the factory. Many countermeasures have been taken after beginning special medical examinations in 1981. First, an impact wrench was suspended by a balancer so that the handle does not need to be held while working (from 1987 to 1988). A mold was introduced that does not require screwing in or unscrewing of bolts (1990). An apparatus was set up seven times to automatically screw in or unscrew bolts (from 1990 to 1999). However, technical improvements in the motors of vibrating tools and introduction of a vibration-proof vibrating tool were not done during the study period.

Countermeasures were also taken at the factory to keep the working environments warm. An impact wrench with an air-heated warm handle was introduced to keep hands warm while working (from 1988 to 1989). A hot well was set up for washing hands in warm water (from 1989 to 1993). Further, a vibration-proof glove was promoted to protect hands while operating tool handles (2005). The rate of Raynaud's phenomenon prevalence was calculated among workers who took a special medical examination each year to observe the effect of countermeasures. The prevalence rate was 0.6% in 1982. This rate increased after 1982 and reached its peak value (6.2%) in 1987, when an impact wrench was suspended by a balancer. Thereafter, the prevalence rate gradually decreased. The prevalence rate was 4.9% in 2008.

**Discussion**

The results of this study made it clear that the incidence rate of Raynaud's phenomenon was around 6 persons per 1,000 person-years and that the estimated risk of developing Raynaud's phenomenon showed no increase until 12 yr after starting to operate an impact wrench under various countermeasures for workers using vibrating tools, although the frequency-weighted vibration acceleration of the impact wrenches were higher than the occupational exposure limit value. After that, the estimated risk of developing Raynaud's phenomenon had a tendency to increase exponentially.

One of the important factors that caused Raynaud's phenomenon was the vibration level of the impact wrench. The frequency-weighted vibration acceleration of the impact wrenches in this study corresponded to that reported by Ikeda \textit{et al.}\textsuperscript{21} in 1998. Compared with other hand-held vibrating tools, such as bush cleaners (2–4 m/s\textsuperscript{2})\textsuperscript{22}, the level was not low.

The committee on vibration syndrome of the Japan Society for Occupational Health\textsuperscript{19} recommended the occupational exposure limit value for preventing adverse health effects on workers caused by occupa-

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**Table 2.** Frequency-weighted vibration accelerations and A (8) values of measured impact wrenches

<table>
<thead>
<tr>
<th>Measured tools number</th>
<th>Pickup No.</th>
<th>Frequency-weighted vibration acceleration (m/s\textsuperscript{2})</th>
<th>A (8) (m/s\textsuperscript{2})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1-1S</td>
<td>9.0</td>
<td>5.1</td>
</tr>
<tr>
<td></td>
<td>1-1H</td>
<td>22.6</td>
<td>12.9</td>
</tr>
<tr>
<td></td>
<td>1-2S</td>
<td>11.0</td>
<td>6.3</td>
</tr>
<tr>
<td></td>
<td>1-2H</td>
<td>21.2</td>
<td>12.1</td>
</tr>
<tr>
<td>2</td>
<td>2-1S</td>
<td>4.9</td>
<td>2.8</td>
</tr>
<tr>
<td></td>
<td>3-1S</td>
<td>6.5</td>
<td>3.7</td>
</tr>
<tr>
<td></td>
<td>3-1H</td>
<td>9.0</td>
<td>5.1</td>
</tr>
<tr>
<td>3</td>
<td>4-1S</td>
<td>22.4</td>
<td>12.8</td>
</tr>
<tr>
<td></td>
<td>4-1H</td>
<td>7.5</td>
<td>4.3</td>
</tr>
<tr>
<td>4</td>
<td>5-1S</td>
<td>19.2</td>
<td>10.9</td>
</tr>
<tr>
<td></td>
<td>6-1S</td>
<td>7.2</td>
<td>4.1</td>
</tr>
<tr>
<td>5</td>
<td>7-1S</td>
<td>13.7</td>
<td>7.8</td>
</tr>
<tr>
<td>6</td>
<td>7-1H</td>
<td>8.1</td>
<td>4.6</td>
</tr>
<tr>
<td>7</td>
<td>8-1S</td>
<td>8.5</td>
<td>4.8</td>
</tr>
<tr>
<td>8</td>
<td>8-1H</td>
<td>12.5</td>
<td>7.1</td>
</tr>
</tbody>
</table>

*-1: a way to screw in bolts. *-2: a way to unscrew bolts. *-no number: both a way to screw in and unscrew bolts. S: switch side. H: handle side.
ternal exposure to hand-arm vibration. Fourteen of the 15 pickup points were more than the occupational exposure limit value of 4.9 m/s² for 2.6 h.

New guideline23) was recommended in Japan in 2009 to protect workers using a hand-arm vibrat-
ing tools. This guideline is based on a new concept governed by ISO 534918) and an EU Directive (2002/44/EC)20). As mentioned above, A (8) in the new guideline was recalculated by the vibration exposure time and the frequency-weighted vibration acceleration. The values of A (8) were then compared with the exposure action value (2.5 m/s²) and the exposure limit value (5.0 m/s²), and the risk of vibration exposure was assessed. The results of this study showed that the value of A (8) for 6 pickup points (2.8–4.8 m/s²) were between the exposure action value and exposure limit value, and the value of A (8) for 9 pickup points (5.1–12.9 m/s²) was over the exposure limit value. This shows the necessity for countermea-
sures to decrease the risk of vibration exposure.

In the subject factory, various countermeasures were taken many times. It has been reported7–8) that technical improvements in the motors of vibrating tools and introduction of vibration-proof vibrating tools have drastically reduced the frequency-weighted vibration acceleration in the handles of some vibrating tools. The frequency-weighted vibration acceleration in the handle of a chain saw9, 10), for example, was reduced from 20 m/s² to 2–3 m/s². Longitudinal stud-
ies11) on the effect of changes in vibration acceleration of a chain saw showed a decrease in the occurrence of Raynaud’s phenomenon. Our previous study15) reported that frequency-weighted vibration acceleration decreased after introducing a vibration-proof impact wrench, and the prevalence of Raynaud’s phenomenon then disappeared. In this study, technical improve-
ments in the motors of impact wrenches and intro-
duction of a vibration-proof impact wrench were not performed, although countermeasures were taken many times. Under such conditions, the prevalence rate of Raynaud’s phenomenon did not disappear. It could be speculated that improvement of an apparatus, such as suspending it using a balancer, was not sufficient to resolve Raynaud’s phenomenon.

Countermeasures were also taken to keep the working environments warm. Iwata et al.24) reported that the prevalence of Raynaud’s phenomenon among workers using chain saws was lowered when they were protected against exposure to cold. Although protecting workers from cold exposure was also an important factor15), it was insufficient to prevent the occurrence of Raynaud’s phenomenon.

In this study, operating years at the time of occurrence of Raynaud’s phenomenon were mainly between 20–25 yr. Tomida et al.22) reported that the number of years of occurrence of Raynaud’s phenomenon was 5–10 yr in more than half of the subjects among workers using bush cleaners. Futatsuka et al.25) reported that the prevalence of Raynaud’s phenomenon reached a peak 5 yr after beginning chain saw use. The operating years at the time of occurrence of Raynaud’s phenomenon in this study were longer than those of workers operating bush cleaners and chain saws. The TOT at the time of occurrence of Raynaud’s phenomenon was also longer than that in workers using a bush cleaner22), although the variation level was not low compared with that of bush cleaner.

On the Stockholm Workshop scale, the stage of Raynaud’s phenomenon was almost mild in these workers. On the other hand, the stage of Raynaud’s phenomenon of the workers mainly operating bush cleaners was severe in more than half of the subjects22).

The workers using vibrating tools such as a bush cleaner or chain saw were mainly working in outdoor working environments while operating the tools22, 24). The subjects in this study were working inside the factory while operating the tools. The operating years and the TOT at the time of occurrence of Raynaud’s phenomenon were longer than those of the workers in outdoor working environments. The Raynaud’s phenomenon was mild. These could be the effect of preventing exposure to cold.

The incidence rate of Raynaud’s phenomenon by the person-year method would be 6.27 persons if we could observe 1,000 persons for a year. This incident is higher than that of workers using a bush cleaner (4.48 persons per 1,000 person-years)22). This may result from the higher vibration level compared with the bush cleaner.

The estimated risk of developing Raynaud’s phenomenon was around 0.002 to 0.004 until 12 yr after starting to operate an impact wrench. The vibration level under the occupational exposure limit value induced an incidence rate in 3% after 10 yr19). This value corresponds to a cumulative incidence of 0.003 (3 onsets of 100 persons for 10 operating years). The estimated risk in this study was the same, although the vibration level exceeded the occupational exposure limit value. This may result from the effects of countermeasures at the factory.

The estimated risk of developing Raynaud’s phenomenon showed an exponential increase starting from 12 yr of operation. The beginning of the increase was later than that among workers using a bush cleaner22). This may also result from the effects of countermeasures at the factory. The occupational exposure limit was focused on the 10-year duration19). Our findings could suggest that we should take into account a more extended exposure period when work-
ing conditions are improved.

In conclusion, the incidence rate of Raynaud’s phenomenon in workers using an impact wrench was not higher than that of workers using a bush cleaner, and the estimated risk of developing Raynaud’s phenomenon showed no increase until 12 yr after beginning operation. This may result from the effects of countermeasures taken at the factory because the vibration level exceeded the occupational exposure limit value. However, even under such conditions, the estimated risk of developing Raynaud’s phenomenon increases exponentially after 12 yr of operation. Further studies are needed to clarify better regulation of working environments and health management to prevent the occurrence of Raynaud’s phenomenon after a long exposure to vibration.

References