

Effects of the Atomic Bomb Explosion in Nagasaki : A Medical Perspective¹

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ABSTRACT : A review of the medical effects of the Nagasaki atomic bomb explosion encountered between 1945 and 1990 was conducted. In the early stage, severe and various manifestations due to a combination of heat rays, blast and radiation were detected, but the accurate number of deaths among victims during this early period remains obscure. Keloid scars, cataract, leukemia, thyroid cancer, breast cancer and lung cancer have been established as diseases related to the atomic bomb explosion. Recent epidemiologic investigations show that the incidence of other diseases such as gastric cancer and skin cancer are also relatively high among atomic bomb survivors in Nagasaki.

INTRODUCTION

Forty-five years have passed since the explosion of an atomic bomb (A-bomb) over Nagasaki on August 9, 1945. In 1986, the nuclear power plant accident at Chernobyl, U.S.S.R. served as a warning to humanity that the threat of injury due to radiation is global and that it is not confined to nuclear weapons. The medical knowledge concerning the acute effects of the atomic bombings of Hiroshima and Nagasaki proved invaluable in dealing with the victims of the Chernobyl accident, and the data on late effects is expected to contribute greatly to long-term treatment programs.

Thus, it is considered worthwhile to review the medical effects of the A-bomb explosion in Nagasaki. A-bomb victims and survivors are

called Hibakusha, which is Japanese word that has come into common use in English. Hibakusha showed and still show a variety of symptoms and diseases.

CHRONOLOGICAL CLASSIFICATION

Although there are certain differences of opinion among investigators, A-bomb diseases can be classified chronologically as shown in **Table 1**.

The early stage of A-bomb disease consists of four stages or phases.

Stage I, or the early stage of the acute phase, or the acute phase in the strict sense, is the period up to 14 days after the bombing. Stage IIa, or the middle stage of the acute phase, or the subacute phase in the strict sense, is the period from 15 to 35 days. Stage IIb, or the

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Table 1. Chronological Classification of A-Bomb Disease

| |
|--|
| Early stage of A-bomb disease |
| Stage I (Early stage of acute phase, acute phase in strict sense): 0-14 days |
| Stage II |
| Stage IIa (Middle stage of acute phase, sub-acute phase): 15-35 days |
| Stage IIb (Middle stage of acute phase, sub-chronic phase): 36-60 days |
| Stage III (Late stage of acute phase, chronic phase): 61-120 days (end of 1945) |
| Late A-bomb diseases |
| Late A-bomb diseases (in the strict sense) |
| Intrauterine exposure |
| Others (neoplasm, etc.) |

middle stage of the acute phase, or the sub-chronic phase in the strict sense, is the period from 36 to 60 days. Stage III, or the late stage of the acute phase, or the chronic phase in the strict sense, is the period from 61 to 120 days, which coincides with the end of 1945.

Late A-bomb diseases are those which occurred later than 4 months after the bombing. These consist of aftereffects or late effects of A-bomb disease in the strict sense, intrauterine exposure and other disorders such as malignant tumors.

EARLY STAGE OF A-BOMB DISEASE

Stage I: The accurate number of deaths among Hibakusha during this early period remains obscure. By the end of 1945, approximately seventy-thousand Hibakusha had died in Nagasaki⁷⁾ (**Table 2**), or about one-half the number of victims in Hiroshima. About 90% of those deaths occurred within the first 2 weeks. Hibakusha exposed very near the hypocenter were instantly burnt to death by the fierce heat rays, which also caused raging fires all over the city. As a result, persons badly wounded and unable to move were burnt to death. Many people were buried under the debris of demolished houses. A large proportion of the victims who were not killed instantly died within

Table 2. Number of Casualties due to the A-Bomb in Nagasaki* as of Dec. 1945

| | |
|----------|---------|
| Killed | 73,884 |
| Injured | 74,909 |
| Affected | 120,820 |

* It is unknown whether the transient population, including military personnel and other volunteer corps, is included.
(Section of Research and Statistics, Dept. of General Affairs, Nagasaki City, 1959)

Table 3. Incidence of Symptoms in the Acute Phase

| Symptom | Dead (n=333) | Alive (n=5520) |
|---------------------------|--------------|----------------|
| fever | 80.0% | 21.5% |
| diarrhea | 67.6 | 33.3 |
| vomiting | 51.6 | 15.0 |
| hemorrhage | 48.6 | 14.7 |
| stomatitis | 43.6 | 17.8 |
| headache | 39.0 | 20.4 |
| epilation | 29.1 | 11.8 |
| abdominal pain | 26.1 | 10.8 |
| dizziness | 21.3 | 10.5 |
| consciousness disturbance | 21.0 | 6.6 |

(Oct.-Dec., 1945: modified from Shirabe)

a few days.

Many of these Hibakusha showed symptoms¹²⁾ of fever, severe diarrhea, vomiting, hemorrhage, severe stomatitis and so on (**Table 3**). Commonly detected for two days after the A-bomb explosion, vomiting was experienced by the Hibakusha who died within a few days. These people also complained of severe watery-bloody diarrhea, which simulated dysentery and appeared within one week. High fever was also detected within one week. Hibakusha with a fever of more than 40 degrees centigrade were not uncommon. About 72% of the Hibakusha, many of whom died without external injuries, showed high fever. This fever was considered to be a result not only of injuries, burns and diarrhea but also of direct disturbances in the sweat glands themselves.

Hemorrhagic tendency was a specific symptom of Hibakusha in the early stage of A-bomb disease. Subcutaneous hemorrhages in the form of small patches, bloody stool, hemorrhage from the gingiva, nasal hemorrhage, hematoemesis and hematuria were commonly seen.

Pathologically, the bone marrow and lymph nodes were severely affected. The bone marrow showed a marked hypocellular pattern. Follicles of the lymph nodes were atrophic to the point of disappearance. Necrosis, de-epithelization, focal ulceration and atypical cells of the mucosa of the small intestine were clearly evident. Superficial mucosal necrosis and erosion of the large intestine were frequently found. The bloody diarrhea seemed to be caused by these morphological alterations. The testes and ovaries, which have a high radiosensitivity, showed prominent atrophic changes.

Necrosis, erosion and blister formation of the skin due to heat rays frequently combined with bacterial infection. Therefore, the healing process of burns with complicated manifestations was delayed. In severe cases, ballooning of the alveolar space caused by heat rays fused to form emphysematous changes and showed severe dyspnea.

Stage IIa: During the stage IIa period, radiation injuries were most characteristic in symptoms as well as in pathological findings. The bone marrow disturbance, fever, diarrhea, hemorrhage, stomatitis and general fatigue that appeared in the first stage became even more intensified.

It was during this period that epilation appeared frequently among the Hibakusha, although a few people suffered epilation as early as one week after the bombing. The onset of epilation is most common during the 3rd week, but after the 5th week it gradually decreases⁹⁾ (Fig. 1). The duration of epilation was usually one or two weeks. The nearer to hypocenter the point of exposure, the more frequent the occurrence of epilation. The hair of the head is most commonly affected, but the beard, whiskers, axillar hair and pubic hair were also affected in severe cases. A few days after the onset of epilation, fever, subcutaneous hemorrhage⁹⁾, gingival hemorrhage and nasal bleeding were combined in many cases. Histopathologically, the epidermis and sweat glands were also severely injured. The deeper portion of the hair shafts composed of the hair matrix was atrophied as a direct effect of radiation. Consequently, the hair matrix could not develop into hair sheath and hair cells.

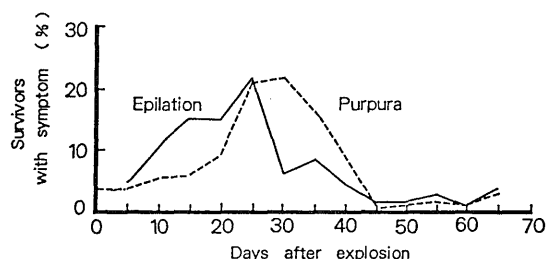


Fig. 1. Days from Explosion to Onset of Epilation and Purpura (modified from Oughterson & Warren, 1956)

It is well known that bone marrow is extremely sensitive to radiation. Leukocytopenia became prominent after about a week. Pathologically, the bone marrow showed a remarkable hypocellular pattern. The examination of peripheral blood smears revealed a decrease in lymphocytes and then a decrease in granulocytes, erythrocytes, and thrombocytes. As a result of this condition, Hibakusha were prone to infections and bleeding.

Stage IIb: This stage corresponded to the period of 36 to 60 days after the bombing. In general, Hibakusha with mild symptoms were beginning to recover by this period. The number of deaths also decreased. The recovery began in the tissues which are most sensitive to radiation. Regeneration of the bone marrow was seen in this phase, although maturation was still incomplete. The bleeding tendency and fever were gradually alleviated. Hair growth began to return from about the 8th week.

Stage III: The third stage consisted of the days from the middle of October to the end of December 1945. Although functional disturbances due to severe trauma persisted, the traumatic wounds themselves began to heal. Severe burn lesions revealed scar, but mild lesions recovered with a covering by regenerated epithelium. However, the affected skin seemed dark in color, because the basal portion of the epidermis showed an increase of melanin pigment, histologically.

The onset of keloid in the region of healing burns was observed in this stage. Since the typical protruding keloid was evident in the period from 6 months to 1 year after the A-bombing, the description for keloid are described in the next phase of late A-bomb disease.

Most cases of epilation recovered in the third stage, that is, 12 to 14 weeks after the bombing.

LATE A-BOMB DISEASE

After the year of the A-bombing, 1945, passed, it seemed that the symptoms of early A-bomb disease had exhausted themselves and that visible disturbances had all but disappeared. But Hibakusha continued to show and still show a variety of symptoms and diseases. This is not surprising when we consider that they were subjected to heat rays, blast and radiation at the same time in various ways. The diseases that continued to show variable symptoms later than 4 months after the bombing are called late atomic bomb diseases.

Keloid: Keloid is the curious protruding lesion that appears elevated lesion protruding more than 3mm. If less than this it was called "hypertrophic scar". The onset of most keloids was in October or November, that is, 2 or 3 months after the A-bombing, but the symptoms became severe 6 to 14 months after the A-bombing. At the time of a 2-year-follow-up study, the raised lesions had involuted into small lesions or disappeared. The majority of Hibakusha with keloid had been exposed within 2 or 2.5km of the hypocenter¹¹⁾ (**Table 4**). The most common locations were the forearm, upper arm, shoulder, foot, face, leg and chest (**Table 5**). Although other types of keloid scar persist and may even extend beyond the site of the original injury, the A-bomb keloid flattened spontaneously in the course of about 2 years. This is the only difference between the two lesions. It has been reported recently that malignant tumor of the skin is more frequent in Hibakusha than in nonexposed persons¹⁰⁾.

Cataract: It is well known that the eye lens is one of the most sensitive tissues to radiation and that cataracts due to radiation are common. A-bomb cataract was frequently observed among proximally exposed Hibakusha and was one of the earliest detectable lesions among late A-bomb diseases. One patient, a 13-year-old boy exposed at 750m from the hypocenter, complained of visual disturbance 10 months after exposure. Two years and 3 months after exposure, he visited an ophthalmologist and

Table 4. Keloid According to the Exposed Distance (Aug.~Sept., 1946)

| Distance | Number of cases |
|----------|-----------------|
| ~1.0km | 7 |
| 1.1~1.5 | 26 |
| 1.6~2.0 | 88 |
| 2.1~2.5 | 30 |
| 2.6~3.0 | 4 |
| 3.1~ | 1 |
| Total | 156 |

(modified from Shirabe & Tezuka, 1959)

Table 5. Keloid Incidence According to its Location

| Region | Numbers | % |
|-------------|---------|-------|
| Forearm | 85 | 20.2 |
| Upper arm | 66 | 15.7 |
| Shoulder | 47 | 11.2 |
| Foot | 43 | 10.2 |
| Head & Face | 38 | 9.1 |
| Leg | 32 | 7.6 |
| Chest | 29 | 6.9 |
| Neck | 26 | 6.2 |
| Hand | 21 | 5.0 |
| Femoral | 17 | 4.0 |
| Lumbosacral | 16 | 3.9 |
| Total (156) | 420 | 100.0 |

(modified from Shirabe & Tezuka, 1959)

received a diagnosis of early phase cataract. This was the earliest reported, and so the onset of A-bomb cataract was probably around 10 months after the A-bombing¹³⁾. The severity and incidence of A-bomb cataract might be related to exposed dose²⁾ (**Table 6**), distance from the hypocenter and age at exposure.

Effects on Females: In female Hibakusha just after exposure, an irregularity of menstruation was noticed and there was a close correlation between the incidence of menstrual abnormality and the distance from the hypocenter⁹⁾ (**Table 7**). Most of the females who complained of these symptoms did not show any further menstrual abnormality 6 months after the A-bombing.

Abnormalities in conception and delivery were also noticed^{9, 16)}. The proportion of abortion and premature delivery was 25.4% among Nagasaki Hibakusha but only about 10% among the general population of Japan at that time (**Table 8**). It can be said, therefore, that the incidence

Table 6. Frequency of Lens Opacity of Polar Region in Relation to Estimated Radiation Doses and Exposure Status

| Estimated Radiation Dose (cGy) | With Acute Radiation Symptoms (%) | Without Acute Radiation Symptoms (%) | Number of Opacities per Number of Cases Examined |
|--------------------------------|-----------------------------------|--------------------------------------|--|
| 0-49 | 17.4 | 5.3 | 5/42 (11.9%) |
| 50-99 | 22.2 | 31.3 | 9/34 (26.5%) |
| 100-199 | 56.5 | 41.9 | 26/54 (48.1%) |
| 200-499 | 58.1 | 42.9 | 21/38 (55.3%) |
| 500 and over | 90.0 | — | 9/10 (90.0%) |
| Total | 48/105 (45.7%) | 22/73 (30.1%) | 70/178 (39.3%) |

(modified from Hirose & Okamoto, 1961)

Table 7. Changes in Menstruation and Amenorrhea in Relation to Distance, Nagasaki

| Distance | Number of Cases | Change in Menstruation | | Amenorrhea for More than 1 Month | |
|--------------|-----------------|------------------------|-------|----------------------------------|------|
| | | Number | % | Number | % |
| 0-0.9km | 11 | 11 | 100.0 | 9 | 81.8 |
| 0.9-1.8 | 80 | 70 | 87.5 | 60 | 75.0 |
| 1.8-2.9 | 50 | 33 | 66.0 | 31 | 62.0 |
| 2.9-3.9 | 83 | 41 | 49.4 | 27 | 32.5 |
| 3.9 and more | 102 | 26 | 25.5 | 18 | 17.6 |
| Total | 326 | 181 | 55.5 | 145 | 44.5 |

(modified from Oughterson & Warren, 1956)

Table 8. Abortion and Premature Parturition in Relation to Exposure Distance

| Distance | Number of Conceptions | Abortions Number (%) | Premature Parturition Number (%) | Total Abnormal Terminations Number (%) |
|--------------|-----------------------|----------------------|----------------------------------|--|
| 0-0.9km | 5 | 5 (100.0) | 0 - | 5 (100.0) |
| 0.9-1.8 | 14 | 8 (57.1) | 6 (42.9) | 14 (100.0) |
| 1.8-2.9 | 20 | 14 (70.0) | 1 (5.0) | 15 (75.0) |
| 2.9-3.9 | 35 | 3 (8.6) | 0 - | 3 (8.6) |
| 3.9 and over | 103 | 3 (2.9) | 5 (4.9) | 8 (7.8) |
| Total | 177 | 33 (18.6) | 12 (6.8) | 45 (25.4) |

* These pregnant women were attended for 3 months after the explosion.
(modified from Oughterson & Warren, 1956)

Table 9. Fetal Mortality among Irradiated and Control Groups

| Distance | Group | Number of Conceptions | Number of Abortions | Number of Stillbirths | Fetal Mortality (%) |
|----------|------------------------|-----------------------|---------------------|-----------------------|---------------------|
| 0-2km | With acute symptoms | 30 | 3 | 4 | 23.3 |
| 0-2 | Without acute symptoms | 68 | 1 | 2 | 4.4 |
| 4-5 | Controls | 113 | 2 | 1 | 2.7 |

(modified from Yamazaki et al., 1954)

of abnormal gestation course was higher in Hibakusha than in other females^{9, 16)}.

Intrauterine Exposure: There were 1562 cases of intrauterine exposure in Nagasaki. A fragmentary report was published in 1954 concerning an investigation into the gestation course of 98 females exposed within 2km and that of 113 nonexposed females¹⁶⁾. It was shown that the frequency of abortion and stillbirth was high in Hibakusha with acute symptoms of A-bomb disease (**Table 9**). Mortality among newborn babies and infants was also higher than that among both exposed females without acute symptoms and controls.

It is a well known fact that people with microcephaly often show mental retardation. Microcephaly is one of the most miserable late A-bomb diseases. Fifteen cases of microcephaly have been reported in Nagasaki⁶⁾. Four of the 15 showed mental retardation, and most were exposed earlier than the 18th week of gestation (**Table 10**).

Chromosomal Aberrations: Even after four decades, chromosomal aberrations in peripheral blood cells and marrow cells are detected more frequently in Hibakusha¹⁾ than in nonexposed control cases. (**Table 11**), although there is no evidence that these findings indicate particular pathogenies. Studies for genetic damages in the second generation of Hibakusha are continuing, but these have failed to reveal any significant differences with the general population.

Neoplasm: Studies concerning the malignant tumor as a late effect of radiation exposure are very important. Therefore, many investigations have been conducted into A-bomb related malignant tumors. The surveys clarified that the mortality in some malignancies such as leukemia, thyroid cancer, breast cancer, lung cancer, colon cancer, gastric cancer and pancreatic cancer of female is higher in Hibakusha than in nonexposed controls. As mentioned earlier, it has also been pointed out that skin cancer seems to be more frequent in Hibakusha than in controls¹⁰⁾.

Even before the atomic bombings, it was known that the incidence of leukemia is high among radiologists and x-ray technicians. It was feared, therefore, that leukemia might develop in Hibakusha. From 1950 to 1952,

Table 10. Frequency of Microcephalia According to Gestational Week and Radiation Dose[#]

| Exposure Dose (cGy) | 0-17 Weeks ^{**} | 18+Weeks |
|------------------------------------|--------------------------|----------|
| Not in city or far from hypocenter | 10/246 | |
| 0-9 | 0/1 | 0/9 |
| 10-19 | 0/7 | 0/6 |
| 20-29 | 0/5 | 2/7 |
| 30-39 | 2/4 | 0/6 |
| 40-49 | 0/6 | 0/3 |
| 50-99 | 0/9 | 0/11 |
| 100-149 | 0/2 | 1/5 |
| 150 or over | 8(3)/9 | 2(1)/9 |
| Total | 10(3)/43 | 5(1)/56 |

* Among persons with small head circumferences some also had mental retardation (numbers in parentheses).

** Gestational week at the time of exposure. (modified from Miller & Blot, 1972)

Table 11. Distribution of Cells with Chromosome Aberrations by Dose [Nagasaki]

| Dose (cGy) | Number of Cases | Number of Cells Examined | Number of Cells with Exchange Aberrations* |
|------------|-----------------|--------------------------|--|
| Control | 156 | 14,748 | 128 (0.87%) |
| 1-99 | 57 | 5,472 | 77 (1.41%) |
| 100-199 | 62 | 5,727 | 73 (1.27%) |
| 200-299 | 58 | 5,443 | 117 (2.15%) |
| 300-399 | 30 | 2,753 | 83 (3.01%) |
| 400-499 | 24 | 2,312 | 147 (6.36%) |
| >500 | 16 | 1,566 | 196 (12.52%) |

* Figures in parentheses are percentages of cells examined.

(modified from Awa et al., 1978)

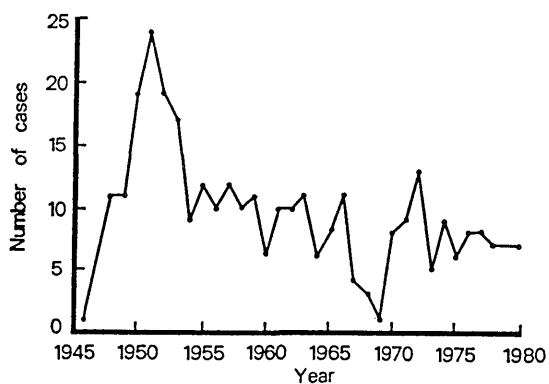


Fig. 2. Leukemia among proximally exposed Hibakusha (within 2km from ground zero: Hiroshima & Nagasaki)

(Ichimaru et al., 1986)

leukemia actually developed with a statistically significant difference³⁾ (Fig. 2). Nowadays, the incidence of leukemia among Hibakusha in Nagasaki is almost the same as that of non-exposed persons. Meanwhile, however, there have been reports suggesting that multiple myeloma in high dose Hibakusha has increased in frequency³⁾.

The incidence of thyroid cancer is high in Hibakusha⁵⁾. Female survivors exposed within 1.5km of the hypocenter and younger than 20 years old at the time of the bombing showed a high incidence of thyroid cancer. The higher the dose, the higher the incidence. Recently, it is said that benign thyroid tumors such as nodular goiter and adenoma are also frequent.

The correlation between dose and breast cancer incidence is linear and almost the same among Nagasaki and Hiroshima survivors¹⁴⁾. The relative risk of A-bomb related breast cancer increased in relation to decreasing age at exposure (less than 10 years old).

The incidence of lung cancer in Hibakusha exposed to a dose of more than 1Gy is significantly higher¹⁵⁾ than that of nonexposed controls. Moreover, the incidence is higher in the 20 to 29 year age group at the time of the bombing.

In recent epidemiologic investigations, colon cancer shows a high incidence among Hibakusha with a high dosage of more than 1Gy and with an age at bombing of younger than 20 years⁸⁾. With regard to Hibakusha in Nagasaki, however, there is no difference between the exposed group and nonexposed group⁴⁾.

In the cancer incidence study conducted during the period from 1950 to 1977, gastric cancer is also a dose-related disease¹⁵⁾. Hibakusha exposed at an age younger than 30 years with a dose of 2Gy or more revealed a high incidence with a relative risk of 1.6.

The knowledge obtained from Hiroshima and Nagasaki is our only means to imagine the catastrophic effects of nuclear warfare. It should be recognized that the experience of Hiroshima and Nagasaki is not merely a past occurrence but an important lesson and grave warning for all mankind.

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