The incidence of human infection with the broad tape
worm *Diphyllobothrium nihonkaiense* has been increas-
ing in urban areas of Japan and in European countries. *D. nihonkaiense* is morphologically similar to but genetically
distinct from *D. latum* and exploits anadromous wild Pacific
salmon as its second intermediate host. Clinical signs in hu-
mans include diarrhea and discharge of the strobila, which
can be as long as 12 m. The natural life history and the
geographic range of the tapeworm remain to be elucidated,
but recent studies have indicated that the brown bear in the
northern territories of the Pacific coast region is its natural fi-
nal host. A recent surge of clinical cases highlights a change
in the epidemiologic trend of this tapeworm disease from
one of rural populations to a disease of urban populations
worldwide who eat seafood as part of a healthy diet.

Broad tapeworms such as *Diphyllobothrium latum* and
*D. nihonkaiense* are exotic parasites that grow as long
as 12 meters in the small intestine. By the mid-19th century,
infection with the Japanese broad tapeworm was known
to be contracted by eating salmon (Figure 1) and was con-
sidered to be infection with *D. latum* until 1986, when Ya-
mame et al. revised the identification of the Japanese broad
tapeworm and established the new species *D. nihonkaiense*
(1). Both tapeworms exploit freshwater copepods as their
first intermediate host. However, in contrast to *D. latum*,
which uses freshwater fish such as perch, char, and pike
as the second intermediate host, *D. nihonkaiense* uses ana-
dromous fish, *Oncorhynchus* spp., such as *O. masou* (masu
salmon), *O. gorbuscha* (pink salmon), and *O. keta* (chum
salmon), which migrate across the northern Pacific Ocean
to the Sea of Okhotsk and the Bering Sea (2,3). Recent stud-
ies have demonstrated complete mitochondrial genomes of
*D. nihonkaiense* and *D. latum* (4,5). These genomes have
not only rendered species diagnosis more reliable, but they
have also provided a wealth of genetic markers that could
be useful for investigating their population genetics, ecol-
ogy, and epidemiology.

*Diphyllobothriasis nihonkaiense* was once endemic
to coastal provinces of central and northern Japan, where
salmon fisheries thrived. However, in the past several
decades, regions with endemic *diphyllobothriasis nihon-
kaiense* have disappeared from Japan, yet the infection
has been perpetuated among urban people who eat sushi
and sashimi. Although the number of clinical cases of the
infection in large cities has fluctuated some in the past 20
years, the incidence was particularly high in 2008. More-
over, clinical cases caused by *D. nihonkaiense* have been
emerging even in European countries (6–9), suggesting that
the globalization of this tapeworm disease is probably due
to the worldwide expansion of commercial sales of fresh or
frozen wild Pacific salmon. We outline the current situation
diphyllobothriasis nihonkaiense in Japan, together with
its still-mysterious ecology and life cycle.

**Recent Surge of Pacific Salmon–
associated Diphyllobothriasis**

We retrospectively examined annual case numbers of
diphyllobothriasis nihonkaiense in 2 institutes; the Depar-
tment of Medical Zoology of the Kyoto Prefectural Uni-
versity of Medicine in Kyoto (MZ) and the Department of
Infectious Diseases of the Tokyo Metropolitan Bokutoh
Hospital (BH) in Tokyo. MZ is the sole institute specializ-
ing in research and diagnosis of parasitic diseases in Kyoto
city (population 1.4 million). BH is one of the major public
hospitals in metropolitan Tokyo.
Diphyllobothriasis Associated with Raw Pacific Salmon

From 1988 through 2008, a total of 149 cases of diphyllobothriasis have been recorded: 95 at MZ and 54 at BH. Diphyllobothriasis nihonkaiense was diagnosed by morphologic appearance and taxonomic characteristics of the strobila (body of the mature tapeworm) passed in feces of a person who had a history of eating salmon or a habit of eating sushi or sashimi, which are normally composed of sea fish, often salmon. DNA sequences of the tapeworm cox1 and/or nad3 genes were also analyzed from most (42) patient specimens obtained since 2004; results confirmed the identification of D. nihonkaiense. Molecularly confirmed D. latum, from humans or fish, has not been reported in Japan.

Annual incidence rates of the clinical cases at MZ and BH show an apparent surge in recent years (Figure 2). In a broad assumption that the case numbers at MZ represent all cases of this tapeworm infection in Kyoto, the average incidence in the past 20 years was 0.32 cases per 100,000 population per year, and that in 2008 was 1.0 case per 100,000 population. Incidence throughout Japan has not been estimated because a nationwide investigation has never been conducted. Nevertheless, these case numbers at MZ and BH suggest that D. nihonkaiense infection is equally as prevalent in Japan as D. latum is in some European countries (10).

Most patients regularly ate sushi and sashimi. Approximately half could recall that they ate raw or undercooked salmon in the past 6 months. Analyses of 149 cases at MZ and BH showed that the disease occurred during all seasons but that prevalence peaked in early summer (Figure 3). Every age group was affected, from 3 to 77 years. Most patients were 20–59 years of age, which probably reflects more frequent consumption of sushi and sashimi by persons in this age group than in other age groups (Figure 4). Twice as many men than women were affected.

Signs and Symptoms of Infection

The signs and symptoms caused by D. nihonkaiense differ little from those caused by D. latum. All 149 patients had consulted physicians after passing tapeworm strobila. Average length of the strobila was 83 cm (range 5–400); patients reported that the strobila tore somewhere along its length when they tried to pull it out. The patients also frequently reported abdominal pain or discomfort and several episodes of diarrhea before passing the strobila, but few complained of substantial weight loss. Of the 149 patients, 73 were treated at MZ, BH, or affiliated institutions. Treatment with anthelmintics (praziquantel for most; bithionol, paromomycin, or sodium amidotrizoate and meglumine amidotrizoate [Gastrografin; Bayer Schering Pharma AG, Berlin, Germany] for a few with older cases) showed that 69 (95%) of 73 patients were infected with 1 tapeworm, 2 were infected with 2 tapeworms, and 2 were infected with 3 tapeworms. The tapeworms obtained measured 50–1,200 cm (average 334 cm). The length of the strobila was not associated with the age or sex of the patient, suggesting that all age groups and both sexes are equally susceptible to this tapeworm.

Pernicious (megaloblastic) anemia has been reported in some patients infected with D. latum (11). Among the patients with D. nihonkaiense infection reported here, low hemoglobin concentration (<12 g/dL) was found in 2 of 43 patients examined. Mild eosinophilia (absolute count >600/μL) was also found in 4 of 37 patients examined. A causal relationship between the anemia or eosinophilia and diphyllobothriasis nihonkaiense for these patients was not determined because neither the type of anemia nor the outcome of anemia or eosinophilia after treatment was examined.

Wild Pacific Salmon and Risk for Diphyllobothriasis Nihonkaiense

Approximately half of the wild Pacific salmon sold in Japan are caught in the coastal areas of northern Japan, and...
the freshwater zooplanktonic copepod 14 that the first intermediate host of 14). 14 sea (14). pleurocercoids were found in masu salmon juveniles that showed a plerocercoid infection rate of 20%, although no of mature masu salmon captured in the rivers in Hokkaido loaded at Japanese ports. To the contrary, an investigation been captured in the waters off the coast of Japan and un- probably originated from rivers in Russia despite having infection was 27%. They suggested that these masu salmon harboring diphyllobothrid plerocercoids; rate of (13), whether freshwater is the place of transmission of the parasite from the copepod to salmon remains controver- sial. Some researchers have been examining a hypothesis that Japanese masu salmon are infected with the plerocer- coид not in freshwater but in the sea during their migration through the Sea of Okhotsk, possibly through another intermediate host that links the freshwater copepod and the wild salmon at sea (14). So far, no such intermediate host has been discovered.

Geographic Distribution of D. nihonkaiense

Until recently, diphyllobothriasis nihonkaiense had been reported almost exclusively in Japan. In northern communities bordering the Pacific, several additional diphyllobothriid species—D. klebanovskii, D. ursi, D. latum, D. dendriticum, and D. dalliae—have been implicated in human infections (16–20). In Far East Russia, D. kle- banovskii, which also uses wild Pacific salmon as its sec- ond intermediate host, is the most common cause of human diphyllobothriasis (16,17). Recent molecular studies of the DNA sequences of the 18S rDNA, internal transcribed re- gion 1, cox1, and nad3, clearly indicated the synonymy of D. klebanovskii to D. nihonkaiense, indicating that D. ni- honkaiense is distributed not only in Japan but also in Far East Russia up to the Kamchatka Peninsula and that brown bears are its natural final host (21).

In 1980, on the Pacific coast of the United States, an outbreak of diphyllobothriasis was associated with consump- tion of Pacific salmon (22), but species identification of the tapeworm was not conducted. More recently, several clinical cases diagnosed by tapeworm DNA sequencing as D. nihonkaiense have emerged in Europe (6–8). These patients had eaten raw Pacific salmon, probably imported from the Pacific coast of North America. Another case, in a tourist to North America who had eaten raw sockeye salm- on from British Columbia, was also diagnosed as caused by D. nihonkaiense. (9). These reports suggest a far broader geographic distribution of D. nihonkaiense than previously believed (Figure 5).

Figure 3. Seasonal occurrence of diphyllobothriasis nihonkaiense, 149 cases, Department of Medical Zoology of the Kyoto Prefectural University of Medicine in Kyoto and Department of Infectious Diseases of the Tokyo Metropolitan Bokutoh Hospital in Tokyo, Japan, 1988–2008.

Figure 4. Age distribution of patients with diphyllobothriasis nihonkaiense, Department of Medical Zoology of the Kyoto Prefectural University of Medicine in Kyoto and Department of Infectious Diseases of the Tokyo Metropolitan Bokutoh Hospital in Tokyo, Japan, 1988–2008.
Diphyllobothriasis Associated with Raw Pacific Salmon

However, whether *D. nihonkaiense* in these regions consists of a biologically homogeneous population is still uncertain. The most enigmatic result of the molecular studies of *D. nihonkaiense* cox1 and nad3 genes is the presence of 2 deeply divergent lineages that are not defined by the localities of the samples examined so far (21). Thus, further studies are needed to look for an association between the host species and/or geographic localities and the 2 genotypes of *D. nihonkaiense*.

**Other Diphyllobothrid Tapeworms in Salmon**

*D. nihonkaiense* is not the sole tapeworm species carried by wild Pacific salmon. On the Pacific coast of North America, *D. ursi* has been isolated from brown bears, black bears, and humans (18,19,23,24). The plerocercoid of *D. ursi* is found predominantly in sockeye salmon (*O. nerka*) and occasionally in coho salmon (*O. kisutch*). A major difference between *D. ursi* and *D. nihonkaiense* (*D. klebanovskii*) is that their plerocercoid stage: plerocercoids of *D. ursi* encyst on stomach serosa of salmon (18), and plerocercoids of *D. nihonkaiense* (*D. klebanovskii*) have been found mainly in the body musculature of chum, masu, and pink salmon (1–3). In some South American countries, cultivated Atlantic salmon (*Salmo salar*) have been implicated as the source of *D. latum* infection (25,26).

**Conclusions**

The epidemiology of diphyllobothriasis nihonkaiensis has changed drastically from rural to urban areas because of the rapid expansion of the transport system for fresh and frozen fish to meet a demand for seafood in healthy diets. The uninterrupted occurrence of diphyllobothriasis nihonkaiensis in urban areas implies that the *D. nihonkaiense* tapeworm perpetuates its natural life cycle successfully between salmon and its final host animals in northern territories of the Pacific Ocean; however, its definite natural life cycle remains to be elucidated. Freezing and storing at −20 °C for 7 days or −35 °C until solid and storing at −35 °C for 15 hours is sufficient to kill parasites, although these conditions may not be suitable for freezing particularly large fish, e.g., those thicker than 6 inches (27).

It seems that the general public in Japan is only vaguely aware of the possible risk for parasitic diseases associated with eating sushi and sashimi made from marine fish. Although some information on this health risk is provided through means such as health education programs open to the public or television programs, the emphasis is generally on the risk for anisakiasis, one of the most prevalent parasitic diseases among Japanese. Persons are generally underinformed, especially about the risk of diphyllobothriasis from eating raw salmon. Moreover, people like sushi and sashimi made of never-frozen fish far better than that made from frozen fish. Consumers and retailers should be made aware of the risk for tapeworm infection posed by eating raw or undercooked wild salmon.

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Dr Arizono is a professor of parasitology at Kyoto Prefectural University of Medicine. His research interests focus on the epidemiology and pathogenesis of helminthic diseases.

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Address for correspondence: Naoki Arizono, Department of Medical Zoology, Kyoto Prefectural University of Medicine, Kamikyo-ku, Kyoto 602-8566, Japan: email: arizono@koto.kpu-m.ac.jp