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Current status of *Clonorchis sinensis* and clonorchiasis in Korea: epidemiological perspectives integrating the data from human and intermediate hosts

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Abstract

Clonorchis sinensis is a carcinogenic liver fluke that causes clonorchiasis in humans. Clonorchiasis is prevalent in East Asian countries, and approximately 15–20 million individuals are estimated to be infected with this fluke globally. This review highlights the current status of *C. sinensis* and clonorchiasis in Korea from the epidemiological perspective involving the analysis of humans and intermediate hosts. Despite the recent decline in *C. sinensis* infection rate in Korea, *C. sinensis* infections remain endemic in 5 major river basins (Han-gang, Geum-gang, Seomjin-gang, Yeongsan-gang and Nakdong-gang; gang means river) with a high incidence of cholangiocarcinoma. A noticeable pattern involves increasing mild infections among patients diagnosed positive for *C. sinensis* eggs. The infection rate of *C. sinensis* metacercariae in the second intermediate host, freshwater fish, is also maintained at a substantial level. Thus, the One Health approach integrating different sectors and disciplines is recommended to accelerate and sustain control of *C. sinensis*, thereby leading to successful eradication. Health promotion *via* information dissemination and health education should be extended to prevent the consumption of raw freshwater fish by residents living in high-risk areas.

Introduction

Clonorchis sinensis is the causative pathogen of human clonorchiasis. Humans are typically infected with the zoonotic trematode parasite upon consuming raw or undercooked freshwater fish carrying metacercariae. Clonorchiasis is mainly prevalent in East Asian countries, including Korea, China and northern Vietnam, and approximately 15–20 million individuals are estimated to be infected by the fluke globally (Lun *et al*., 2005; Qian *et al*., 2016; Na *et al*., 2020). The main cause of the endemicity of clonorchiasis is the traditional habit of consuming raw or fermented freshwater fish, which is a significant hurdle in controlling and eliminating the disease in endemic countries.

Clonorchiasis is likely prevalent in Korea during the past decades. Control or elimination of *C. sinensis* infection has been attempted in Korea since 1970s. As a result, the overall prevalence of clonorchiasis in Korea has decreased in recent years; however, it still remains endemic to 5 major river basins and remains a non-negligible parasitic disease affecting human health in Korea. Here, we briefly review the epidemiology of *C. sinensis* and clonorchiasis in humans and intermediate hosts in Korea to provide insights into the current epidemiology of the parasite and the disease in Korea.

Life cycle of *C. sinensis* and its clinical manifestations

C. sinensis eggs are ingested by the freshwater snail, the first intermediate host. The eggs are hatched in its gastrointestinal tract and develop into miracidium. Miracidium proliferates into hundreds of cercariae in the snail, which are then released into the water. The actively swimming cercariae penetrate the second intermediate hosts, freshwater fish, develop into metacercariae in the muscles of freshwater fish, and are subsequently transmitted to definite mammalian hosts (Lai *et al*., 2016).

Among freshwater snails, *Parafossarulus manchuricus* has been recognized as the major first intermediate host in Korea (Choi, 1984). Snail species, such as *P. anomalospiralis*, *Alocinma longicornis*, *Bithynia fushiana*, *B. misella*, *Melanoides tuberculata*, *Assiminea lutea* and *Thiara granifera*, may act as the first intermediate hosts (Lun *et al*., 2005). Snails typically inhabit water bodies with slow flow or stagnant water in moist areas rich in organic sediment and aquatic vegetation.

Humans are the most important definitive hosts of *C. sinensis*. The known reservoir hosts include dogs, cats, rats, pigs, buffaloes, weasels and foxes (Na *et al*., 2020). Several laboratory animals, including rabbits, guinea pigs, hamsters, gerbils and mice, are reportedly susceptible to infection with *C. sinensis* metacercariae (Rim, 1986; Lun *et al*., 2005; Tang *et al*., 2016). Reservoir hosts serve as carriers of *C. sinensis* eggs and contaminate water sources.

Table 1. Changing patterns of intestinal parasitic infections in nationwide surveys in Korea identified by the 'Korea Intestinal Parasite Eradication Program' conducted between 1969 and 2012

					Egg positive rate (%) of helminth			
					C. sinensis			
Year	No. of examinees	Helminth egg positive rate (%)	Cumulative egg rate (%)	STH	Total	Male	Female	Intestinal trematodes
1969	40 581	90.5	149.6	141.5	4.7	5.9	2.4	1.6
1971	24 887	84.3	147.1	131.0	4.6	3.1	1.6	3.2
1976	27 178	63.2	89.6	85.2	1.8	1.3	0.5	0.7
1981	35 018	41.1	54.5	36.9	2.6	1.8	0.8	14.3
1986	43 690	12.9	14.9	7.0	2.5	n.a.	n.a.	4.9
1992	46 912	3.8	3.9	0.5	2.2	1.1	0.5	1.3
1997	45 832	2.4	2.4	0.1	1.4	0.9	0.4	0.9
2004	20 546	4.3	4.4	0.3	2.9	1.9	1.0	1.1
2012	23 956	2.6	2.6	0.4	1.9	1.3	0.7	0.1

STH, soil-transmitted helminths; n.a., not available.
Source: Survey results were collected from the previous report 'Prevalence of intestinal parasitic infections in Korea'.

The ingested metacercariae excyst in the duodenum of the human host, and the newly excysted juveniles rapidly migrate to the intrahepatic bile duct *via* the ampulla of Vater and the common bile duct and develop into adult worms (Kim *et al*., 2011). Adult worms can survive for long periods (~20–30 years) in the bile ducts. During this time, infected individuals manifest diverse clinical symptoms of clonorchiasis resulting from continuous mechanical irritations of worms or chemical stimulations of excretory–secretory products (ESPs) (Na *et al*., 2020). The severity of symptoms varies depending on the worm burden, infection period and re-infection frequency. Common clinical manifestations at the initial stage include mild fever, diarrhoea, abdominal discomfort, malaise and anorexia. In serious and chronic infections, jaundice, biliary inflammation and bile duct obstruction are observed, resulting in cholangitis, cholelithiasis and cholangiectasis (Lun *et al*., 2005; Na *et al*., 2020). The parasite can also induce irreversible pathological changes or damage in the hepatobiliary tract. Hence, *C. sinensis* has also been recognized as a biological carcinogen that causes cholangiocarcinoma (CCA) by the International Agency for Research on Cancer (IARC) (Bouvard *et al*., 2009).

High prevalence of clonorchiasis in the 5 major river basins in Korea

C. sinensis, along with soil-transmitted helminths (STH), is likely prevalent in Korea for a long time as its eggs were discovered in ancient ruins and mummies (Zhan *et al*., 2019; Oh *et al*., 2021). Human helminthiasis was highly prevalent in Korea until the 1970s, when the *per capita* helminth parasite infection rate was estimated to be approximately 150% (Cho *et al*., 2014a). The most prevalent helminth parasites were intestinal helminths, including STH, such as *Ascaris lumbricoides*, hookworms, and *Trichuris trichiura* and food-borne helminths, such as *C. sinensis, Metagonimus yokogawai* and tapeworms. To eliminate intestinal helminthic infections, the Korean Association for Parasite Eradication (KAPE; renamed the Korea Association for Health Promotion) was established in 1964. The Korean Government promulgated the 'Parasitic Disease Prevention Act' in 1966 (Lee, 2007). In 1969, the first scientific report demonstrated that the national average positive rate for the presence of *C. sinensis* eggs was 4.7% (Table 1). However, a positive rate of 22% was observed in 40,581 residents of the 5 major river basins (Han-gang, Geum-gang, Seomjin-gang, Yeongsan-gang and Nakdong-gang; gang means river) with the highest positive rate of 48.1% in the Nakdong-gang area (Seo *et al*., 1969).

Since the 'Korea Intestinal Parasite Eradication Program', which includes intensive health education and active screening of infected individuals followed by mass chemotherapy, began in 1971, the overall prevalence of STH infections has rapidly declined during the past decades in Korea (Cho *et al*., 2014a) (Table 1). Based on the positivity rate of *C. sinensis* eggs in the examined population, the nationwide prevalence of *C. sinensis* infection was estimated to be 4.6% in 1971. Subsequently, the rate gradually decreased (Hong and Yong, 2020).

Initiation of the Korea intestinal parasite eradication program

Nationwide application of praziquantel in 1983 led to a significant decrease in the prevalence of *C. sinensis* (Seo *et al*., 1983). The declining prevalence of *C. sinensis* infections during the past decades may also be attributed to the strengthened health promotion and educational measures undertaken widely in endemic regions since 1973 (Lee, 2007; Cho *et al*., 2014a; Hong and Yong, 2020). However, compared to the dramatic decline in other helminthic infections, especially STH infections, during the last few decades in Korea, the *C. sinensis* infection rate has remained a serious public health concern. Indigenous infections are still highly prevalent in the major river basins. In these regions, the prevalence is much higher than the national average infection rate. This suggests that *C. sinensis* is not distributed evenly throughout the country but is rather prevalent in endemic areas alongside the major river basins (Fig. 1). To finally eradicate fish-borne trematodes, including *C. sinensis*, and survey their second intermediate fish hosts, Korea Disease Control and Prevention Agency (KDCA; formerly known as Korea Centers for Disease Control and Prevention) launched the 'Phase II Korea Intestinal Parasite Eradication Program' in 2005 (Cho *et al*., 2016). Similar to the previous 'Korea Intestinal Parasite Eradication Program', this programme conducted a large-scale stool examination of inhabitants residing alongside the 5 major river basins in Korea (Cho *et al*., 2016; Ju *et al*., 2017; Shin *et al*., 2020, 2021). The average positive rate of *C. sinensis* eggs was 8.7% over 10 years. These results demonstrated a high prevalence of 7.9–11.1% during

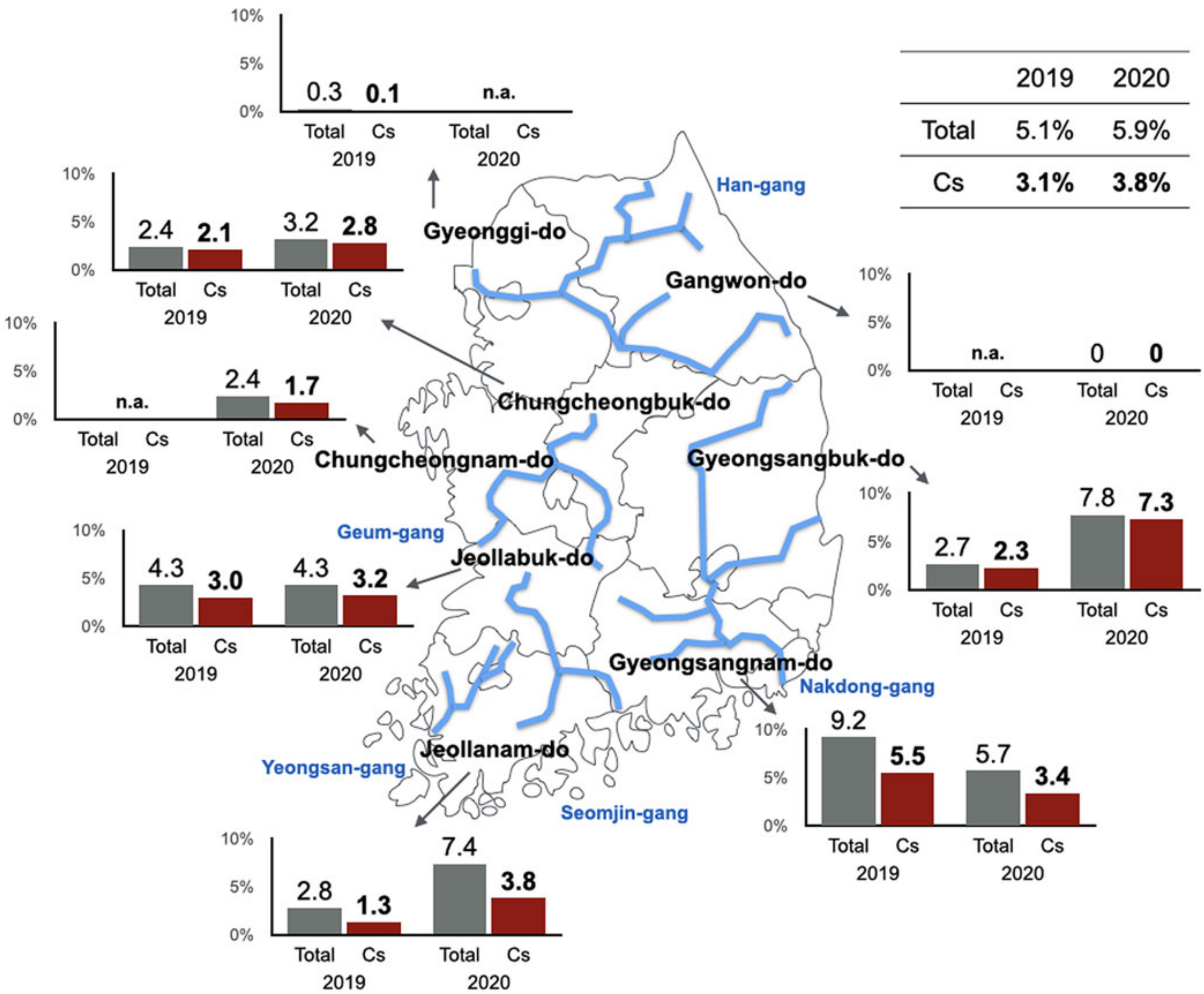

Fig. 1. Latest epidemic map of clonorchiasis in 8 administrative districts of Korea. The map was adapted from the 'Phase II Korea Intestinal Parasite Eradication Program' surveys conducted between 2019 and 2020 (Shin *et al*., 2020; Shin *et al*., 2021). Blue lines indicate major rivers in Korea. Cs, *C. sinensis*; Total, total positive rate of intestinal helminth eggs; do, province; n.a., not available.

2005–2013. However, the prevalence was eventually reduced to 5.1% in 2014 (Table 2) (Cho *et al*., 2016). A recent nationwide survey of *C. sinensis* suggested that the estimated rate of *C. sinensis* infection has slightly decreased to 3.1% in 2019 and 3.8% in 2020 (Fig. 1). However, the rate is much higher among residents residing in Nakdong-gang, Seomjin-gang and Yeongsan-gang, suggesting that clonorchiasis has been a significant burden to health localities and households in the areas of the 3 river basins in Korea (Shin *et al*., 2020, 2021).

Epidemiological characteristics of clonorchiasis in Korea

Statistics examining the prevalence of clonorchiasis in Korea have revealed several epidemiological characteristics. A high positive rate indicating the presence of eggs is typically observed in the elderly population comprising individuals over 50 years old (Cho *et al*., 2008) (Table 3), and re-infection after chemotherapy is also frequently observed in this population, suggesting that the old habit of eating raw freshwater fish from childhood is an important factor contributing to the high risk of *C. sinensis* infection (Rim, 1990). Individuals are typically overconfident in the efficacy of praziquantel and ignore the risks of asymptomatic infection or re-infection (Rim *et al*., 1996). Meanwhile, the infection rate in younger generations (<40 years old) is much lower than that in older generations. General changes in dietary patterns attributed to economic development and health promotion education for awareness of *C. sinensis* and clonorchiasis infections in schools may discourage younger individuals from eating raw freshwater fish. As clonorchiasis is closely associated with the socio-behavioural patterns of raw fish consumption, a higher prevalence of infection is observed in men than in women in all examined generations.

C. sinensis as a causative factor of CCA

A significant correlation between the *C. sinensis* infection rate and CCA cases has also been reported in endemic areas, particularly in Gyeongsangnam-do (province), where Nakdong-gang flows (Choi *et al*., 2006; Lim *et al*., 2006; Shin *et al*., 2010). Among 185 outpatients with CCA, a significant correlation was observed between 167 (90.3%) patients and *C. sinensis* infection based on the radiological diagnosis of *C. sinensis*, history of eating raw freshwater fish and positive serological findings for *C. sinensis* (Choi *et al*., 2006). To investigate the relationship between *C. sinensis* and CCA, the National Cancer Center (NCC) conducted an epidemiological survey (3169 residents; age range, 30–87 years) in 3 areas (Chuncheon, Chungju and Haman) with different CCA mortality rates. The

Table 2. Changing trends in the endemicity of intestinal helminths in the major river basins identified by 'Phase II Korea Intestinal Parasite Eradication Program' between 2005 and 2014

Year	No. of public health localities	No. of examinees	Helminth egg positive rate (%)	Egg positive rate (%) of 3 major helminths		
				C. sinensis	*M. yokogawai*	*T. trichiura*
2005	8	11 196	11.0	9.1	1.7	0.2
2006	23	24 075	14.3	11.1	1.8	0.1
2007	29	31 268	9.5	8.1	0.8	0.1
2008	37	42 562	9.5	8.4	1.0	0.1
2009	37	35 563	12.2	10.8	1.6	0.2
2010	32	33 113	10.9	9.5	0.9	0.3
2011	37	27 733	13.3	11.1	2.7	0.4
2012	34	23 233	9.4	8.0	1.4	0.2
2013	36	38 745	9.5	7.9	1.7	0.2
2014	39	41 909	6.6	5.1	1.3	0.2
2017	32	38 648	4.8	3.9	0.8	0.1
2019	32	30 415	5.0	3.1	1.7	0.2
2020	43	25 642	4.0	3.8	n.a.	0.2
Average	–	–	9.2	7.7	1.3	0.2
Total	419	404 102	–	–	–	–

n.a., not available.
Source: The survey results were collected from previous publications (Cho *et al.*, 2016; Ju *et al.*, 2018; Shin *et al.*, 2020; Shin *et al.*, 2021).

Table 3. Positive rates by age and survey years

Age	0–19	20–29	30–39	40–49	50–59	60–69	70–79	80–89
1971	2.1	4.6	7.7	9.2	9.5*	8.8	n.a.	n.a.
1976	0.8	2.1	3.3*	2.9	3.1	2.3	n.a.	n.a.
1981	0.8	3.0	4.8	5.2*	5.1	3.7	n.a.	n.a.
1992	0.6	1.6	2.5	3.7	3.9*	3.8	n.a.	n.a.
1997	0.2	0.7	1.3	2.6	2.8*	2.5	n.a.	n.a.
2004	0.5	1.2	2.2	4.5	6.5*	4.1	n.a.	n.a.
2012	0.3	1.5	1.9	2.6	3.4*	3.1	2.7	1.1
2014	0.2	2.1	2.9	4.9	7.2*	6.5	4.5	4.2
2017	0.5	1.1	2.5	4.1	5.6*	5.1	3.4	2.3
2019	1.0	1.9	2.1	2.8	4.1	4.5*	3.0	2.8
2020	0.0	0.6	1.4	3.1	4.4	4.6*	4.4	3.6
Average	0.6	1.8	3.0	4.1	5.1*	4.4	3.6	2.8

Asterisk (*) indicate the highest positive rate per year; n.a., not available.
Source: The survey results were collected from the previous report 'Prevalence of intestinal parasitic infections in Korea' and publications (Cho *et al.*, 2016; Ju *et al.*, 2018; Shin *et al.*, 2020; Shin *et al.*, 2021).

highest prevalence of *C. sinensis* (31.3%) was detected in Haman, Gyeongsangnam-do, where the estimated CCA incidence rate was 5.5 per 100 000 individuals (Lim *et al.*, 2006). Eventually, the NCC and Ministry of Health and Welfare (MHW) officially announced that CCA is highly correlated with the high endemicity of *C. sinensis* in Korea (National Cancer Center, 2016).

Light and moderate *C. sinensis* infections function as impediments in controlling clonorchiasis

Despite the steady maintenance of the *C. sinensis* infection rate in Korea, the overall egg burden, determined by the number of eggs per gram of feces in patients with clonorchiasis, has decreased in recent years compared to that in past decades, except for 2 highly endemic areas, Nakdong-gang and Seomjin-gang basins (Shin *et al.*, 2020). Low egg burden in patients implies mild infection or low worm burden. However, it is also an important hurdle for effective control and management of clonorchiasis. An accurate diagnosis followed by proper drug treatment of infected individuals is an efficient measure to obstruct the further transmission of *C. sinensis* infection. However, low egg burden has challenged the effective control of clonorchiasis. In common fecal examination, which is the gold standard diagnostic method for *C. sinensis* infection, patients with low egg burden can occasionally be

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Table 4. Second intermediate hosts of *C. sinensis* in Korea

Family	Genus	Species	References
Cyprinidae	*Abbottina*	*A. rivularis*	Kobayashi (1917)
		A. springeri	Rhee *et al.* (1984)
	Acanthorhodeus	*A. gracilis* (*A. chankaensis*)	Rhee *et al.* (1984)
		A. asmussi (*Acheilognathus asmussi*)	Chun (1962)
		A. macropterus	Sohn *et al.* (2019)
	Acheilognathus	*A. lanceolata* (*Tanakia lanceolata*)	Rim (1986)
		A. signifier	Rim (1986)
		A. rhombeus	Choi (1976)
		A. yamatsutae	Rim (1986)
		A. koreensis (*Tanakia koreensis*)	Sohn *et al.* (2019)
		A. majusculus	Sohn *et al.* (2019)
	Aphyocypris	*A. chinensis*	Rhee *et al.* (1983)
	Carassius	*C. auratus*	Kobayashi (1917)
	Coreoleuciscus	*C. splendidus*	Rhee *et al.* (1983)
	Culter	*C. brevicauda* (*Chanodichthys erythropterus*)	Chun (1962)
	Cyprinus	*C. carpio*	Shin (1964)
	Erythroculter	*E. erythropterus* (*Chanodichthys erythropterus*)	Choi (1976)
	Gnathopogon	*G. strigatus*	Rhee *et al.* (1983)
	Hemiculter	*H. eigenmanni* (*H. leucisculus*)	Rhee *et al.* (1983)
		H. leucisculus	Kim (1968)
	Hemibarbus	*H. labeo*	Lee (1968)
		H. longirostris	Shin (1964)
	Microphysogobio	*M. koreensis*	Rim (1986)
		M. yaluensis	Rhee *et al.* (1983)
	Opsariichthys	*O. uncirostris amurensis* (*O. uncirostris*)	Rim (1986)
	Phoxinus	*P. oxycephalus*	Rhee *et al.* (1983)
	Pseudogobio	*P. esocinus*	Chun (1962)
	Pseudorasbora	*P. parva*	Kobayashi (1917)
	Puntungia	*P. herzi*	Lee and Kim (1958)
	Rhodeus	*R. ocellatus* (*R. ocellatus ocellatus*)	Kim (1974)
		R. pseudosericeus	Kim (1968)
	Saurogobio	*S. dabry*	Joo and Hong (1991)
	Sarcocheilichthys	*S. nigripinnis morii*	Rim (1986)
		S. variegatus wakiyae	Shin (1964)
	Squaliobarbus	*S. curriculus*	Rim (1986)
	Squalidus	*S. japonicus coreanus*	Lee and Kim (1958)
		S. gracilis majimae	Seo (1959).
	Tribolodon	*T. hakonensis*	Chun (1962)
	Zacco	*Z. platypus*	Chun (1962)
		Z. koreanus	Sohn *et al.* (2019)
		Z. temminckii	Chun (1962)
	Ladislabia	*L. taczanowskii*	Cho *et al.* (2014b)
Centrarchidae	*Micropterus*	*Micropterus salmoides*	Sohn *et al.* (2021c)
	Lepomis	*L. macrochirus*	Sohn *et al.* (2021c)
Bagridae	*Coreobagrus*	*C. brevicorpus*	Joo (1980)
Channidae	*Channa argus*	*C. argus*	Sohn *et al.* (2019)

(*Continued*)

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Table 4. (*Continued.*)

Family	Genus	Species	References
Cobitidae	*Misgurnus*	*M. anguillicaudatus*	Sohn *et al.* (2021d)
Leuciscidae	*Rhynchocypris*	*R. oxycephalus*	Cho *et al.* (2014b).
Pristigasteridae	*Ilisha*	*I. elongate*	Rim (1986)
Odontobutidae	*Odontobutis*	*O. platycephala*	Sohn *et al.* (2021a)
Osphronemidae	*Macropodus*	*M. chinensis* (*M. opercularis*)	Hwang and Choi (1980)
Percichthyidae	*Coreoperca*	*C. herzi*	Hwang and Choi (1980)
	Siniperca	*S. scherzei*	Moon *et al.* (2007)
Osmeridae	*Hypomesus*	*H. olidus*	Nam and Sohn (2000)
Gobioninae	*Squalidus*	*S. chankaensis*	Sohn *et al.* (2021d)
		S. multimaculatus	Sohn *et al.* (2021d)
	Hemibarbus	*H. mylodon*	Cho *et al.* (2014b)
	Microphysogobio	*M. jeoni*	Sohn *et al.* (2018)
		M. longidorsalis	Sohn *et al.* (2021c)

determined to false negative (Korea Disease Control and Prevention Agency, 2009).

Several alternative diagnostic approaches to overcome weaknesses of traditional fecal examination method have been proposed. For immunological diagnosis, enzyme-linked immunosorbent assay is one of the most commonly used indirect serodiagnosis methods for *C. sinensis* infections. Soluble extracts or ESPs from adult worms have been employed as antigens to provide reliable diagnostic results (Na *et al.*, 2020). However, such assays based on crude and ESP antigens are difficult to reproduce consistently and show cross-reactivity with infections caused by other trematodes. Many molecularly defined recombinant proteins have been suggested as useful antigens; however, they show moderate sensitivity and specificity. Examples include cysteine proteases (Na *et al.*, 2002; Kang *et al.*, 2010), 7 kDa antigen (Lee *et al.*, 2002), glutathione *S*-transferases (Hong *et al.*, 2002), paramyosin (Park *et al.*, 2009; Kang *et al.*, 2015) and CsAg17 (Cho *et al.*, 2020). With respect to molecular characteristics, diagnosis can be made reliably by detecting *C. sinensis* nucleic acids in stool samples using polymerase chain reaction-based methods (Cho *et al.*, 2013). However, since nucleic acids need to be prepared from samples using specialized kits and devices, these requirements and high costs may be hurdle for local clinics and primary care institutions.

Freshwater fish as intermediate hosts

The reduction in the number of intermediate hosts due to natural environment destruction may have also contributed to the recent decline in *C. sinensis* prevalence. This suggests the importance of investigating the infection status of *C. sinensis* metacercariae in freshwater fish to survey and control intermediate hosts. To date, approximately 60 species of freshwater fish have been identified as second intermediate hosts of *C. sinensis* in Korea (Table 4) (Hong and Hong, 2005; Kim *et al.*, 2008; Sohn, 2009, 2022). The infection rate of *C. sinensis* metacercariae in second intermediate hosts varies by season, region and freshwater fish species. Among the intermediate hosts of *C. sinensis* in Korea, several cyprinid fish species, such as *Puntungia herzi*, *Pseudorasbora parva*, *Squalidus* spp., *Sarcocheilichthys* spp. and *Pseudogobio esocinus*, are highly susceptible to *C. sinensis* infection. Recently, a total of 17 freshwater fish species, including *Squalidus chankaensis*, *S. multimaculatus*, *Hemibarbus mylodon*, *Microphysogobio jeoni*, *M. longidorsalis*, *Ladislabia taczanowskii*, *Acheilognathus koreensis*, *A. majusculus*, *Acanthorhodeus macropterus*, *Rhodeus pseudosericeus*, *Zacco koreanus*, *Rhynchocypris oxycephalus*, *Odontobutis platycephala*, *Channa argus*, *Misgurnus anguillicaudatus*, *Micropterus salmoides* and *Lepomis macrochirus* were newly identified as the second intermediate hosts for *C. sinensis* in Korea (Table 4) (Kim, 1974; Cho *et al.*, 2014b; Sohn *et al.*, 2018, 2019, 2021a, 2021b, 2021d). Notably, 2 exotic freshwater fish species, *M. salmoides* (large-mouth bass) and *L. macrochirus* (blue gill), were recently identified to harbour *C. sinensis* metacercariae (Sohn *et al.*, 2021c). Both species were first introduced in Korea in the 1970s and have since spread to freshwater systems throughout the country. Further investigation on the mechanisms by which both freshwater fish species influence the infectivity of *C. sinensis* is necessary.

The infectivity of *C. sinensis* metacercariae in freshwater fish varies by region. It is generally low or moderate in freshwater fish in Han-gang and its streams (Cho *et al.*, 2011, 2014b; Sohn *et al.*, 2015) and Geum-gang (Cho *et al.*, 2011). Higher parasite infection rates have been found in freshwater fish obtained from Yeongsan-gang, Tamjin-gang and Seomjin-gang in Jeollanam-do (Cho *et al.*, 2011). Freshwater fish from Nakdong-gang in Gyeongsangbuk-do and Gyeongsangnam-do also showed high infection levels with *C. sinensis* metacercariae (Sohn *et al.*, 2021d, 2021e) (Fig. 2). These patterns are highly correlated with the prevalence of human clonorchiasis.

Interdisciplinary One Health approach for eradication of *C. sinensis*

The control of *C. sinensis* and clonorchiasis has been successful in Korea. However, the control of the endemicity of *C. sinensis* is also necessary in some areas. The endemicity should probably be less than 1% for eradication. Recently, the One Health concept has been highly recommended for the integrated control of food-borne trematode infections by the World Health Organization expert consultation in Korea (WHO, 2017). One Health programme involves the collaboration of professionals across different disciplines aiming to adopt the best health measures for individuals, animals and the environment (Sripa *et al.*, 2017). Controlling zoonotic diseases requires interdisciplinary One Health approaches encompassing various sectors and disciplines, such as public health, veterinary medicine, clinical medicine, molecular biology, fisheries and malacology (Blake and Betson, 2017) (Fig. 3). Successful impact of the One Health approach has been

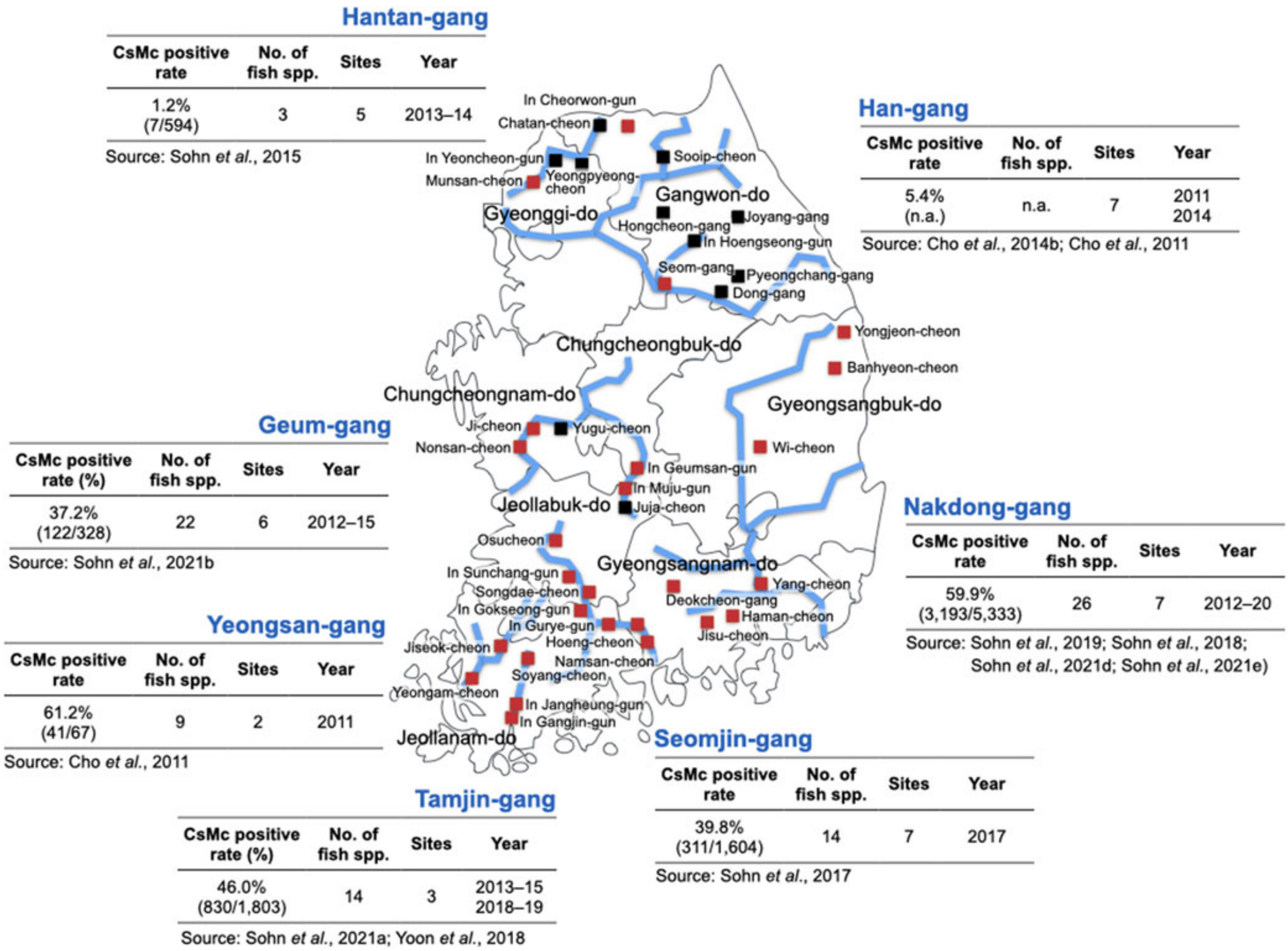

Fig. 2. Infection rate of freshwater fish in the major river basins. The infection status was adapted from previous surveys as described in each reference. Rectangles indicate survey areas for freshwater fish collection. Red and black indicate positivity and negativity for *C. sinensis* eggs, respectively. Blue lines indicate major rivers in Korea. CsMs, *C. sinensis* metacercariae; cheon, stream; do, province; gun, county; n.a., not available.

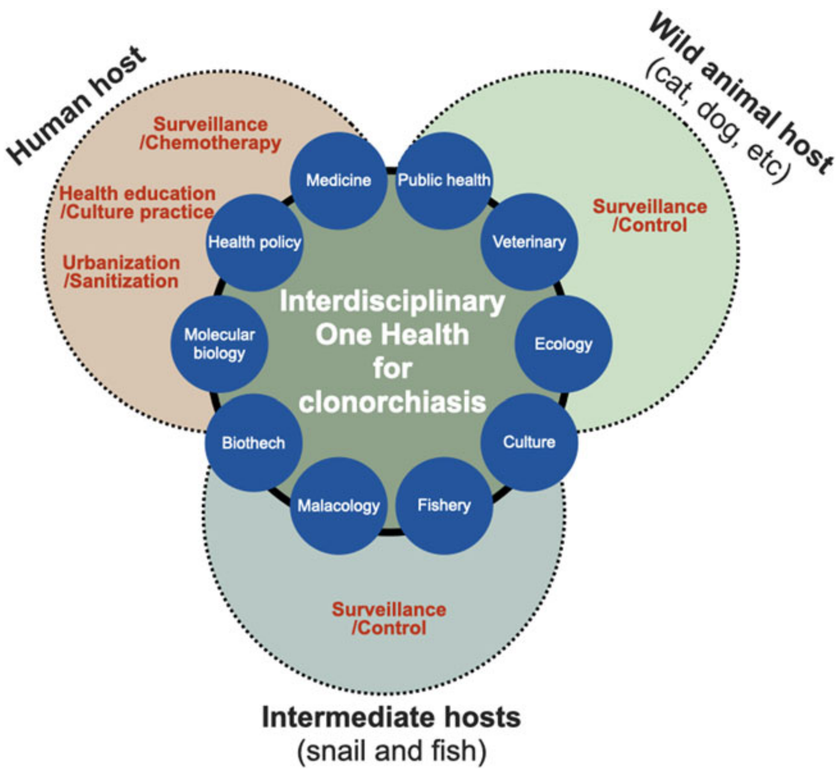

Fig. 3. Interdisciplinary One Health approach to accelerate effective control and eradication of *C. sinensis* infections. The One Health concept can be characterized as the approach involving the collaboration between professionals across different disciplines for the optimal health of individuals, animals and the environment.

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demonstrated in the Lawa model, Khon Kaen, Thailand (Sripa *et al*., 2017). The core strategy involved animal and human treatment, interventions based on influencing the ecosystem, food safety, hygiene and effective risk communication to accelerate and sustain the control of food-borne trematode infections.

First, wild and domestic animals in river areas may function as reservoirs or definite hosts of *C. sinensis*, and they are crucial factors in maintaining the life cycle of the parasite in the natural environment, contributing to the continuous endemicity of clonorchiasis (Min, 1981; Choe *et al*., 2019). The nationwide positive rate of clonorchiasis was 1.4% in pigs, 2.4% in dogs and 1.9% in cats, whereas Gyeongsangnam-do showed the highest prevalence of 5.8, 6.1 and 4.5%, respectively (Min, 1981). Thus, veterinary surveillance should be performed to understand the spread of clonorchiasis from humans to animals and vice versa. KDCA operates Clo-Net to manage patient data with clonorchiasis and VectorNet to implement vector surveillance, although both are not yet open to the public at present. Therefore, it is necessary that the government extend the current surveillance system and open it for public purposes.

Second, the top priority is to end the cultural dietary habit of eating raw freshwater fish, which contributes to the persistent transmission of the fish-borne trematode to humans. The practice of consuming raw or undercooked freshwater fish has persisted for thousands of years in endemic regions (Oh *et al*., 2021). Health promotion *via* informational programmes and education, such as publicity materials and educational videos ('Do not eat raw freshwater fish' URL: https://youtu.be/llqIwPhMcTU) among residents residing in the highly endemic river areas, should be strengthened to change their eating habits with cooperative efforts of the KDCA, local government and public health professionals.

Third, cases of light and moderate *C. sinensis* infections remain a challenge for accurate diagnosis owing to insufficient sensitivity and difficulty in identifying morphologically similar parasite species in fecal samples. Moreover, fecal examination method is unsuitable for large-scale surveys because of the time- and labour-intensive tasks involved inevitably. Thus, the development and application of simple and sensitive diagnostic methods to detect patients, especially low worm burden individuals, are urgently needed. In the era of artificial intelligence, deep-learning-based egg recognition may be an alternative method to differentiate *C. sinensis* eggs from the eggs of other intestinal trematodes (Jiménez *et al*., 2020). Collaboration between several disciplines and biotechnology to develop simple, easily adaptable on-site and reliable diagnostic methods may contribute to mass surveys (Ju *et al*., 2016; Yoo *et al*., 2020).

Concluding remarks

Clonorchiasis is a preventable parasitic disease among individuals who do not consume raw freshwater fish. However, a non-negligible prevalence of the disease is still observed in Korea, especially among the inhabitants of the 5 major river basins. Case confirmation in the field is difficult, and confirmed cases are incompletely cured owing to treatment failure or re-infection. In the wake of the increasing number of mild infections, a health concept that considers an interdisciplinary approach is required to control and eliminate *C. sinensis* and clonorchiasis in Korea. Health promotion *via* increasing awareness and health education to prevent the consumption of raw freshwater fish among residents living in high-risk areas is also necessary.

Data availability. The original data in the present study are available from the corresponding author upon request.

Author contributions. WGY and BKN designed the study. WGY, WMS and BKN conducted data gathering. WGY, WMS and BKN wrote the article.

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Conflict of interest. None.

Ethical standards. None.

References

Blake DP and Betson M (2017) One Health: parasites and beyond. *Parasitology* **144**, 1–6.

Bouvard V, Baan R, Straif K, Grosse Y, Secretan B, El Ghissassi F, Benbrahim-Tallaa L, Guha N, Freeman C, Galichet L and Cogliano V (2009) A review of human carcinogens – part B: biological agents. *Lancet Oncology* **10**, 321–322.

Cho SH, Lee KY, Lee BC, Cho PY, Cheun HI, Hong ST, Sohn WM and Kim TS (2008) Prevalence of clonorchiasis in southern endemic areas of Korea in 2006. *Korean Journal of Parasitology* **46**, 133–137.

Cho SH, Sohn WM, Na BK, Kim TS, Kong Y, Eom K, Seok WS and Lee T (2011) Prevalence of *Clonorchis sinensis* metacercariae in freshwater fish from three latitudinal regions of the Korean Peninsula. *Korean Journal of Parasitology* **49**, 385–398.

Cho PY, Na BK, Choi KM, Kim JS, Cho SH, Lee WJ, Lim SB, Cha SH, Park YK, Pak JH, Lee HW, Hong SJ and Kim TS (2013) Development of a polymerase chain reaction applicable to rapid and sensitive detection of *Clonorchis sinensis* eggs in human stool samples. *Pathogens and Global Health* **107**, 253–259.

Cho SH, Chung BS and Lee SE (2014a) National survey of intestinal parasitic infections in Korea, 8th report 2013. *Public Health Weekly Report* **7**, 89–94 (in Korean).

Cho SH, Lee WJ, Kim TS, Seok WS, Lee T, Jeong K, Na BK and Sohn WM (2014b) Prevalence of zoonotic trematode metacercariae in freshwater fish from Gangwon-do, Korea. *Korean Journal of Parasitology* **52**, 399–412.

Cho SH, Shin HE, Lee SE and Park MY (2016) Survey on the prevalence of intestinal parasitic infections in Korea, 2014. *Public Health Weekly Report* **9**, 118–124 (in Korean).

Cho PY, Lee JY, Kim TI, Song JH, Hong SJ, Yoo WG, Tsuboi T, Ha KS, Jung JW, Takeo S, Han ET, Sripa B, Hong ST, Chai JY, Nam HW, Pak JH and Kim TS (2020) Serodiagnostic antigens of *Clonorchis sinensis* identified and evaluated by high-throughput proteogenomics. *PLoS Neglected Tropical Diseases* **14**, e0008998.

Choe S, Jeong DH, Yang JJ, Kim J, Na KJ, Lee D, Park H, Jeon HK and Eom KS (2019) A clonorchiasis case of a leopard cat, *Prionailurus bengalensis euptilurus*, diagnosed by ultrasonography and egg detection in Republic of Korea. *Korean Journal of Parasitology* **57**, 299–302.

Choi DW (1976) *Clonorchis sinensis* in Kyungpook province, Korea: 2. Demonstration of metacercaria of *Clonorchis sinensis* from fresh-water fish. *The Korean Journal of Parasitology* **14**, 10–16.

Choi DW (1984) *Clonorchis sinensis*: life cycle, intermediate hosts, transmission to man and geographical distribution in Korea. *Arzneimittel-Forschung* **34**, 1145–1151.

Choi D, Lim JH, Lee KT, Lee JK, Choi SH, Heo JS, Jang KT, Lee NY, Kim S and Hong ST (2006) Cholangiocarcinoma and *Clonorchis sinensis* infection: a case-control study in Korea. *Journal of Hepatology* **44**, 1066–1073.

Chun S (1962) Studies on some trematodes whose intermediate hosts are fishes in the Naktong river. *Bulletin of Fish Collection* **4**, 21–38.

Hong ST and Hong SJ (2005) *Clonorchis sinensis* and clonorchiasis in Korea. *Food-Borne Helminthiasis in Asia. Asian Parasitology* **1**, 35–56.

Hong ST and Yong TS (2020) Review of successful control of parasitic infections in Korea. *Infection & Chemotherapy* **52**, 427–440.

Hong SJ, Yun Kim T, Gan XX, Shen LY, Sukontason K, Sukontason K and Kang SY (2002) *Clonorchis sinensis*: glutathione *S*-transferase as a serodiagnostic antigen for detecting IgG and IgE antibodies. *Experimental Parasitology* **101**, 231–233.

Hwang J and Choi D (1980) Changing pattern of infestation with larval trematodes from freshwater fish in river Kumho, Kyungpook Province, Korea. *Kyunpook University Medical Journal* **21**, 460–475.

Jiménez B, Maya C, Velásquez G, Barrios JA, Pérez M and Román A (2020) Helminth egg automatic detector (HEAD): improvements in development for digital identification and quantification of helminth eggs and its application online. *MethodsX* **7**, 101158.

Joo CY (1980) Epidemiological studies of *Clonorchis sinensis* in vicinity of river Taewha, Kyungnam province, Korea. *The Korean Journal of Parasitology* **18**, 199–214.

Joo CY and Hong YA (1991) Epidemiological studies of *Clonorchis sinensis* in the vicinity of River Ahnseong, Kyungpook Province, Korea. *The Korean Journal of Parasitology* **40**, 542–552.

Ju JW, Lee MR, Cho SH and Park MY (2016) Improvement and recent status of clonorchiasis diagnostics development. *Public Health Weekly Report* **9**, 206–210 (in Korean).

Ju JW, Lee MR, Shin HE and Cho SH (2017) The status of *Clonorchis sinensis* infection in Korea: what should be done to eliminate clonorchiasis? *Public Health Weekly Report* **10**, 1–6 (in Korean).

Ju JW, Lee MR, Shin HE, Kim YJ, Lee SE, Kim HJ, Bahk SO, Lee YJ and Cho SH (2018) Current status of the elimination project on intestinal parasitic diseases in endemic areas with food-borne trematodiasis. *Public Health Weekly Report* **11**, 426–432 (in Korean).

Kang JM, Bahk YY, Cho PY, Hong SJ, Kim TS, Sohn WM and Na BK (2010) A family of cathepsin F cysteine proteases of *Clonorchis sinensis* is the major secreted proteins that are expressed in the intestine of the parasite. *Molecular and Biochemical Parasitology* **170**, 7–16.

Kang JM, Ju HL, Lee J, Kim TI, Cho SH, Kim TS, Sohn WM and Na BK (2015) Mapping of the putative epitope domain of *Clonorchis sinensis* paramyosin (CsPmy) recognized by CsPmy-specific immunoglobulin G in sera of human clonorchiasis. *Molecular and Biochemical Parasitology* **201**, 66–71.

Kim DC (1974) Ecological studies of *Clonorchis sinensis* – endemicity and propagation of clonorchiasis in high and low endemic areas in Korea. *Yonsei Reports on Tropical Medicine* **5**, 3–44.

Kim EM, Kim JL, Choi SY, Kim JW, Kim S, Choi MH, Bae YM, Lee SH and Hong ST (2008) Infection status of freshwater fish with metacercariae of *Clonorchis sinensis* in Korea. *Korean Journal of Parasitology* **46**, 247–251.

Kim TI, Yoo WG, Kwak BK, Seok JW and Hong SJ (2011) Tracing of the bile-chemotactic migration of juvenile *Clonorchis sinensis* in rabbits by PET-CT. *PLoS Neglected Tropical Diseases* **5**, e1414.

Kobayashi H (1917) On the life-history and morphology of the liver distome (*Clonorchis sinensis*) *Mitteil. aa Mediz. Fachschule z. Keijo*, 251–284.

Korea Disease Control and Prevention Agency (2009) Recent prevalence of clonorchiasis in some riverside regions of Korea. *Public Health Weekly Report* **2**, 232–237.

Lai DH, Hong XK, Su BX, Liang C, Hide G, Zhang X, Yu X and Lun ZR (2016) Current status of *Clonorchis sinensis* and clonorchiasis in China. *Transactions of the Royal Society of Tropical Medicine and Hygiene* **110**, 21–27.

Lee JT (1968) Studies on the metacercariae from fresh water fishes in the Kum-Ho river. *The Korean Journal of Parasitology* **6**, 77–99.

Lee SH (2007) Transition of parasitic diseases in Korea. *Journal of the Korean Medical Association* **50**, 937–945 (in Korean).

Lee SK and Kim KS (1958) An epidemiological study of *Clonorchis sinensis*. *Journal of Taegu Medical Society* **1**, 1–7 (in Korean).

Lee HJ, Lee CS, Kim BS, Joo KH, Lee JS, Kim TS and Kim HR (2002) Purification and characterization of a 7-kDa protein from *Clonorchis sinensis* adult worms. *Journal of Parasitology* **88**, 499–504.

Lim MK, Ju YH, Franceschi S, Oh JK, Kong HJ, Hwang SS, Park SK, Cho SI, Sohn WM, Kim DI, Yoo KY, Hong ST and Shin HR (2006) *Clonorchis sinensis* infection and increasing risk of cholangiocarcinoma in the Republic of Korea. *American Journal of Tropical Medicine and Hygiene* **75**, 93–96.

Lun ZR, Gasser RB, Lai DH, Li AX, Zhu XQ, Yu XB and Fang YY (2005) Clonorchiasis: a key foodborne zoonosis in China. *The Lancet Infectious Diseases* **5**, 31–41.

Min HK (1981) An epidemiological study on zoonoses in Korea. *The Korean Journal of Parasitology* **19**, 60–75.

Moon HD, Na BK and Sohn WM (2007) Infection status of trematode in residents of riverside villages and in freshwater fishes from Gyeonghogang (River) in Sancheong-gun. *Korea. Gyeongsang Institute of Health Sciences Journal* **3**, 187–204.

Na BK, Lee HJ, Cho SH, Lee HW, Cho JH, Kho WG, Lee JS, Lee JS, Song KJ, Park PH, Song CY and Kim TS (2002) Expression of cysteine proteinase of *Clonorchis sinensis* and its use in serodiagnosis of clonorchiasis. *Journal of Parasitology* **88**, 1000–1006.

Na BK, Pak JH and Hong SJ (2020) *Clonorchis sinensis* and clonorchiasis. *Acta Tropica* **203**, 105309.

Nam HS and Sohn WM (2000) Infection status with trematode metacercariae in pond smelts, *Hypomesus olidus*. *Korean Journal of Parasitology* **38**, 37–39.

National Cancer Center (2016) A first report on nationwide map and statistics of cancer distribution in South Korea.

Oh CS, Lee H, Kim J, Hong JH, Cha SC, Chai JY, Ha CM, Kang RJ, Lim DS, Shin DH and Seo M (2021) Two helminthic cases of human mummy remains from Joseon-period graves in Korea. *Korean Journal of Parasitology* **59**, 149–152.

Park TJ, Kang JM, Na BK and Sohn WM (2009) Molecular cloning and characterization of a paramyosin from *Clonorchis sinensis*. *Korean Journal of Parasitology* **47**, 359–367.

Qian MB, Utzinger J, Keiser J and Zhou XN (2016) Clonorchiasis. *Lancet (London, England)* **387**, 800–810.

Rhee JK, Lee HI, Baek BK and Kim PG (1983) Survey on encysted cercariae of trematodes from fresh-water fishes in Mangyeong riverside area. *The Korean Journal of Parasitology* **21**, 187–192.

Rhee JK, Rim MH, Baek BK and Lee HI (1984) Survey on encysted cercaria of trematodes from fresh-water fishes in Tongjin riverside areas in Korea. *The Korean Journal of Parasitology* **22**, 190–202.

Rim HJ (1986). The current pathobiology and chemotherapy of clonorchiasis. *The Korean Journal of Parasitology* **24**, 1–141.

Rim HJ (1990). Clonorchiasis in Korea. *The Korean Journal of Parasitology*, **28** (Suppl), 63–78.

Rim HJ, Kim KH, Joo KH, Kim SJ, Eom KS and Chung MS (1996) The infestation states and changing patterns of human infecting metacercariae in freshwater fish in Kyongsang-do and Kyonggi-do, Korea. *Korean Journal of Parasitology* **34**, 95–105.

Seo BS (1959) The *in vitro* excystation of metacercariae of *Clonorchis sinensis*. *New Medical Journal* **2**, 65–73.

Seo BS, Rim HJ, Loh IK, Lee SH, Cho SY, Park SC, Bae JW, Kim JH, Lee JS, Koo BY and Kim KS (1969) Study on the status of helminthic infections in Koreans. *The Korean Journal of Parasitology* **7**, 53–70.

Seo BS, Lee SH, Chai JY and Hong ST (1983) Praziquantel(Distocide(R)) in treatment of *Clonorchis sinensis* infection. *The Korean Journal of Parasitology* **21**, 241–245.

Shin DS (1964) Epidemiological studies of *Clonorchis sinensis* prevailed in the peoples of Kyungpook province. *The Korean Journal of Parasitology* **2**, 1–13.

Shin HR, Oh JK, Lim MK, Shin A, Kong HJ, Jung KW, Won YJ, Park S, Park SJ and Hong ST (2010) Descriptive epidemiology of cholangiocarcinoma and clonorchiasis in Korea. *Journal of Korean Medical Science* **25**, 1011–1016.

Shin HE, Lee MR, Bahk SO, Lee YJ, Ju JW and Lee H (2020). The current status of the elimination project on intestinal parasitic diseases in 2019. In Public Health Weekly Report, Vol. 13, pp. 2141–2148. Korea Centers for Disease Control and Prevention.

Shin HE, Bahk SO, Lee YJ, Ju JW and Lee H (2021) The infection status of intestinal parasites and the degree of infection risk of freshwater fish in 2020. *Public Health Weekly Report* **14**, 1696–1706 (in Korean).

Sohn WM (2009) Fish-borne zoonotic trematode metacercariae in the Republic of Korea. *Korean Journal of Parasitology*, **47**(Suppl), S103–S113.

Sohn WM (2022) Infection characteristics of *Clonorchis sinensis* metacercariae in fish from Republic of Korea. *Korean Journal of Parasitology* **60**, 79–96.

Sohn WM, Na BK, Cho SH, Lee SW, Choi SB and Seok WS (2015) Trematode metacercariae in freshwater fish from water systems of Hantangang and Imjingang in Republic of Korea. *Korean Journal of Parasitology* **53**, 289–298.

Sohn WM, Na BK, Cho SH, Park MY, Kim CH, Hwang MA, No KW, Yoon KB and Lim HC (2017) Prevalence of *Clonorchis sinensis* metacercariae in fish from water systems of Seomjin-gang (River). *Korean Journal of Parasitology* **55**, 305–312.

Sohn WM, Na BK, Cho SH, Ju JW and Son DC (2018) Prevalence and intensity of *Clonorchis sinensis* metacercariae in freshwater fish from Wicheon Stream in Gunwi-gun, Gyeongsangbuk-do, Korea. *Korean Journal of Parasitology* **56**, 41–48.

Sohn WM, Na BK, Cho SH and Ju JW (2019) Infection status with *Clonorchis sinensis* metacercariae in fish from Yangcheon (Stream) in Sancheong-gun, Gyeongsangnam-do, Korea. *Korean Journal of Parasitology* **57**, 145–152.

Sohn WM, Na BK, Cho SH, Ju JW, Kim CH, Hwang MA, No KW and Park JH (2021a) Prevalence and infection intensity of zoonotic trematode metacercariae in fish from Soyang-cheon (Stream), in Wanju-gun, Jeollabuk-do, Korea. *Korean Journal of Parasitology* **59**, 265–271.

Sohn WM, Na BK, Cho SH, Kim CH, Hwang MA, No KW and Kim JD (2021b) Survey of zoonotic trematode metacercariae in fish from water systems of Geum-gang (River) in Republic of Korea. *Korean Journal of Parasitology* **59**, 23–33.

Sohn WM, Na BK, Cho SH, Lee HI, Ju JW, Lee MR, Lim EJ, Son SY, Ko E and Choi J (2021c) Survey of zoonotic trematode metacercariae in fish from irrigation canal of Togyo-jeosuji (Reservoir) in Cheorwon-gun, Gangwon-do, Republic of Korea. *Korean Journal of Parasitology* **59**, 427–432.

Sohn WM, Na BK, Cho SH, Lee HI, Ju JW, Lee MR, Park JG and Ahn J (2021d) Endemicity of zoonotic trematode metacercariae in fish from Deokcheon-gang (River) in Sancheong-gun, Gyeongsangnam-do, Republic of Korea. *Korean Journal of Parasitology* **59**, 523–529.

Sohn WM, Na BK, Cho SH, Lee HI, Lee MR, Ju JW and Kim GO (2021e) High endemicity with *Clonorchis sinensis* metacercariae in fish from Yongjeon-cheon (Stream) in Cheongsong-gun, Gyeongsangbuk-do, Korea. *Korean Journal of Parasitology* **59**, 97–101.

Sripa B, Tangkawattana S and Sangnikul T (2017) The Lawa model: a sustainable, integrated opisthorchiasis control program using the ecohealth approach in the Lawa lake region of Thailand. *Parasitology International* **66**, 346–354.

Tang ZL, Huang Y and Yu XB (2016) Current status and perspectives of *Clonorchis sinensis* and clonorchiasis: epidemiology, pathogenesis, omics, prevention and control. *Infectious Diseases of Poverty* **5**, 71.

WHO. Regional Office for the Western Pacific (2017) Expert consultation to accelerate control of foodborne trematode infections, taeniasis and cysticercosis, Seoul, Republic of Korea, 17–19 May 2017: meeting report.

Yoo WG, Kang JM, Le HG, Pak JH, Hong SJ, Sohn WM and Na BK (2020) Bile ductal transcriptome identifies key pathways and hub genes in *Clonorchis sinensis*-infected Sprague-Dawley rats. *Korean Journal of Parasitology* **58**, 513–525.

Yoon KB, Lim HC, Jeon DY, Park S, Cho SH, Ju JW, Shin SS, Na BK and Sohn WM (2018) Infection status with *Clonorchis sinensis* metacercariae in fish from Tamjin-gang (River) in Jeollanam-do, Republic of Korea. *Korean Journal of Parasitology* **56**, 183–188.

Zhan X, Yeh HY, Shin DH, Chai JY, Seo M and Mitchell PD (2019) Differential change in the prevalence of the *Ascaris*, *Trichuris* and *Clonorchis* infection among Past East Asian populations. *Korean Journal of Parasitology* **57**, 601–605.