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☐ **Mini-Review** ☐

Epidemiological understanding of *Taenia* tapeworm infections with special reference to *Taenia asiatica* in Korea

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Abstract: In endemic areas of *Taenia* tapeworms in Korea, most of the reports showed that *T. saginata* was dominant over *T. solium*, but eating pigs is the dominant habit over eating cattle. Why do they have more *T. saginata* despite lower consumption of beef? This problem actually has long been recognized but until recently there has been no intensive trial to give a scientific explanation on this epidemiological enigma. By summing up the data published between the years 1963 and 1999, the ratio of armed versus unarmed tapeworms in humans was estimated at approximately 1:5. The ratio of pig-eaters versus cattle-eaters, however, was approximately 5:1. This inconsistency could be explained with the recently described *T. asiatica*, which infects humans through the eating of pig's viscera. We re-evaluate the importance of the consumption of visceral organ of pigs, leading us to an improved epidemiological understanding of the *T. asiatica* infection together with co-existing *T. saginata* and *T. solium* in Korea.

Key words: *Taenia asiatica*, *T. saginata*, *T. solium*, tapeworm, taeniasis, Asian tapeworm, epidemiological inconsistency

INTRODUCTION

Taenia tapeworm, according to the definition of the World Health Organization, is 'cyclo-zoonotic parasite' transmissable between vertebrates and humans. Sprent (1969) defined this group as 'anthropozoonotic helminths' due to the fact that humans spread the parasites as a final host. Garnham (1958) considered it euzoonosis, because humans are indispensable in the life cycle of *Taenia* tapeworms. Human taeniasis is distributed worldwide, and the beef tapeworm *T. saginata* is regarded as dominant over *T. solium* (Refuerzo and Albis, 1947; Arambulo, 1967, 1971).

Korea is also known to be *T. saginata* dominant country, even though there is an apparent epidemiological inconsistency between the species ratio and the eating habits of intermediate hosts (Eom, 1991). In areas of *Taenia* tapeworm endemicity, most of the reports show that *T. saginata* is dominant over *T. solium*, but consumption of pigs dominates over that of cattle. Yet, why do they have more *T. saginata* despite the lower consumption of cattle? Many Korean researchers recognized this inconsistency long ago (Park and Chyu, 1963; Kang et al., 1965a; Lee et al., 1966; Cho

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et al., 1967; Han, 1969; Kim, 1980, 1982; Joo et al., 1985; Soh et al., 1988). And the most peculiar example of all the areas with this problem was Sorokdo Island, located in the southernmost peninsula of Korea in which no cattle are reared (Hong et al., 1983).

We approached this question with available references, covering prevalence and species distribution of *Taenia* tapeworms, and the eating habit of raw foods since 1915 in the most important endemic areas within Korea, to clarify the picture of inconsistency.

Recently there was a description of a third human tapeworm, *Taenia asiatica* Eom et Rim 1993, a species whose possible existence had been noted since 1935 in Taiwan. This parasite was found to be infective as a larval form in the liver of Korean domestic pigs, and as adult form in the intestines of humans. With the eggs from a volunteer, pigs were infected in the visceral organs with living metacestodes, but only calcified ones were found in the liver of cattle (Eom et al., 1992). Fan et al. (1995) redescribed it as *T. saginata asiatica* on the basis of morphological similarity to *T. saginata*, and on which arguments are continuing. Unfortunately, even recent molecular biological studies show conflicting results and do not support the insistence for either species or subspecies. Some researchers argue for species level, while others for subspecies. Recently, however, support for recognition at species level is gaining, however more time is needed to accumulate further data for definitive answers.

The life cycle of the Asian tapeworm (*T. asiatica*), is reported to have a striking difference in having viscerotropism instead of musculotropism (Eom et al., 1992; Eom and Rim, 1993). *T. asiatica* is thought to be transmissable only through the liver and visceral organs, and not through the muscle of intermediate hosts; while *T. solium* and *T. saginata* are transmissible through pork and beef, respectively. This Asian tapeworm is thought to be distributed in many Asian countries, and it may even occur on other continents too. However, isolates of *T. asiatica* from many countries require careful evaluation especially on genetic variations.

T. asiatica thus can be a clue to solve the epidemiological inconsistency between the species ratio of tapeworms and the eating habit of intermediate hosts in Korea. This problem actually has long been recognized and addressed by researchers far before *T. asiatica* was recognized. However, until recently there has been no attempt to give a scientific explanation for this epidemiological enigma with the use of *T. asiatica*.

We believe this approach could be successfully applied to address epidemiological problem, and may also be applied to other countries having the same kind of epidemiological questions about *Taenia* tapeworms.

EPIDEMIOLOGICAL INCONSISTENCY OF TAENIA TAPEWORM INFECTIONS IN KOREA

The epidemiological inconsistency of *Taenia* tapeworm infections among Korean people could be recognized by calculating the species ratio of adult *Taenia* tapeworms, and the habit of eating raw foods of the intermediate hosts. An example observed in Sorokdo Island of Southern Korea clearly showed this kind of inconsistency (Hong et al., 1983).

Prevalence of intestinal *Taenia* tapeworms

Prevalences of human taeniasis since 1915 in Korea are summarized in Table 1. There are other records not summarized in this table because of insufficient detail of description. In a report of Inoba (1924), prevalences of *Taenia* tapeworms among Koreans were quoted as 16% from author Handa, 7-8% from Mine, without description of locality or date. Probably they were small sized surveys done before 1924. Somewhat detailed prevalence data of *Taenia* tapeworms among Koreans were accumulated until 1929, so it was not difficult to understand about the tapeworm status of those days. In 1930s, research almost ceased, except focal surveys started again from 1945. It was, however, not until the 1960s that more substantial surveys for parasites began. Most of the data collected in the 1960s were from local surveys, although those by Soh et al. (1961) and Lee et al. (1966)' were relatively large scale. In 1969, Seo et al.

Table 1. Prevalence of human taeniasis by coprological examinations in Korea surveyed between the years 1915 and 1997

Authors	Years	Localities and subjects	Number of cases		Prevalence (%)
			Examined	Positives	
Matsumoto	1915	Taegu	351	13	3.7
Kobayashi & Kwon[a]	1917	Kyongsong Hospital[b]	323	29	9.0
Provincial office[a]	1922	Hamkyongnam-do	600	10	1.7
Yabe et al.[a]	1923	Taegu[b]	323	6	1.9
Inoba[a]	1923	Huichon-gun[c]	102	3	2.9
	1924	Namhae[d]	100	6	6.0
Hara & Yoshino	1924	Kyongsangnam-do	1,141	24	2.1
Government general[a]	1925	Chollabuk-do[e]	1,592	16	1.0
Choi[a]	1927	Kyongsong	4,000	12	0.3
Koyama[a]	1927	Kyongsangnam-do	192	7	3.6
Mills[a]	1927	Kyonggi-do	7,000	201	2.9
Oda	1929	Chonju[f]	442	14	3.2
Miwa	1935a	Kanggye[c]	596	4	0.7
Miwa	1935b	Mokpo[g]	862	3	0.3
Nishimura	1943	Taegu[h]	341	2	0.6
Hunter et al.	1949	Seoul, inhabitants	169	2	1.2
Choi et al.	1949	Chollanam-do[i]	150	2	1.3
Brooke et al.	1956	South Korea	919	16	1.7
Lee et al.	1960	Taegu[j]	384	3	0.8
Soh et al.	1961	Seoul[b]	14,682	73	0.5
Rim	1963	Wonju, Kangwon-do[k]	1,963	39	2.0
Jeong	1964	Namwon[b], [f]	250	7	2.8
Lee et al.	1966	Okku[f], [i]	803	32	4.0
		Sunchang[f], [i]	542	33	6.1
Lee & Ryang	1967	Taegu[k]	239	5	2.1
Yun et al.	1968	Taegu[j], [l]	1,370	15	1.1
Park et al.	1969	Wonju, Kangwon-do[k]	1,012	15	1.5
Seo et al.	1969	South Korea	40,581	284	0.7
Kim et al.	1970	Koreans in Vietnam[k]	433	5	1.2
		South Korea[k]	114	1	0.9
Choi et al.	1971	Kyongsangbuk-do[b]	5,288	33	0.6
Cho et al.	1969	South Korea	1,843	27	1.5
Kim et al.	1971	South Korea	2,250	7	0.3
KAPE[s]	1971	1st National survey[u]	24,887	461	1.9
Im et al.	1972	Taegu[k], [m]	2,073	12	0.6
Seo et al.	1972	Cheju-do	3,169	402	12.7
Lee	1973	South Korea	3,822	61	1.6
Choi et al.	1974	Military zone[k]	17,775	75	0.4
Lim et al.	1975	Koesan-gun[i], [n]	608	5	0.8
KAPE	1976	2nd National survey[u]	27,178	197	0.7
Seo et al.	1977	Pochon-gun[o]	141	1	0.7
		Chinyang-gun[d]	147	0	0
Choi et al.	1979	Kyongsangbuk-do	1,066	4	0.4
Joo	1979	South Korea[k], [m]	3,330	23	0.7
Kim	1980	Provinces[f], [n], [p]	790	26	3.3
Rim et al.	1980	Seoul, Provinces[d], [n]	1,946	40	2.1
KAPE	1981	3rd National survey[u]	35,018	389	1.1
Seo et al.	1981	South Korea	13,373	67	0.5

Table 1. continued

Authors	Years	Localities and subjects	Case numbers of		Prevalence (%)
			Examined	Positives	
Chai et al.	1982	Kyonggi-do, Taegu[k]	411	3	0.7
Rhee et al.	1983	Mankyonggang basin[f]	1,266	27	2.1
Bae et al.	1983	Namgang basin[d]	5,291	28	0.5
Hong et al.	1983	Sorokdo[g, i, q]	2,026	69	3.4
Rhee et al.	1984	Tongjingang basin	923	48	5.2
Joo	1984	Taegu[i]	1,697	11	0.6
Choi et al.	1984	Masan, Kongju[r]	329	2	0.6
Joo et al.	1985	Seoul[i, l]	4,256	4	0.1
		Cheju-do[i, l]	1,280	50	3.9
Min et al.	1986	Hanyang University[b]	5,251	0	0
KAH[t]	1986	4th National survey[u]	43,590	119	0.3
Hong	1986	Taegu, Seoul[k]	2,643	8	0.3
Goo et al.	1988	Yochon-gun[g, i]	1,011	59	5.8
KAH	1992	5th National survey[u]	46,912	26	0.06
KAH	1997	6th National survey[u]	45,832	11	0.02

[a]Some of the references are indirect citation from Oda (1929) or others; [b]Out patients; [c]Pyonganbuk-do; [d]Kyongsangnam-do; [e]Rural inhabitants; [f]Chollabuk-do; [g]Chollanam-do; [h]Middle school students; [i]*Inhabitants*; [j]*Elementary school students*; [k]*Soldiers*; [l]*Students*; [m]*Military medical college*; [n]Chungchongbuk-do; [o]Kyonggi-do; [p]Chungchongnam-do; [q]Leprosarium; [r]Tuberculosis patients and workers; [s]Korea Association of Parasite Eradication (KAPE); [t]Korea Association of Health (KAH); [u]Prevalence of intestinal parasitic infections in Korea published by Ministry of Health and Welfare, and KAH (former KAPE).

conducted the first nationwide parasitological survey, including most of the provinces, and thus it could be regarded as one of the most important reports after the Second World War. It was revealed that 0.7% of Koreans were positive for taeniid eggs. Carefully prepared is this survey, dealing with total 40,581 individuals including adequate sample sizes for male/female comparisons, as well as with military soldiers. The only limitation of this survey is that there was a serious bias for the 5-29 year-old age group, comprising 96% of all subjects, making it difficult to call it a real nationwide survey representing all age groups of Koreans (Table 1). Thereafter nationwide surveys were conducted every five years, revealing taeniid egg positives of between 0.02 and 1.9%, with fluctuation varying greatly, causing difficulties in figuring out trends (Table 1).

Ratio of numbers of *Taenia solium* and *T. saginata*

Morphological similarity between taeniid eggs makes it difficult to determine the species ratio between *T. solium* and *T. saginata*. Gravid proglottids spread eggs irregularly through the proctostoma (Mazzotti, 1947; Rijpstra et al., 1961), and distribute them unevenly into stools, causing a lower detection rate than real cases (Lee, 1970; Rim, 1980). Possible ways to make differential diagnosis are observing the number of main uterine branches, and the motility of gravid proglottids, as well as observing the hooklets on the scolex. Kang et al. (1965a) reported that *T. saginata* is more common than *T. solium*, with as much as 86.9% out of 327 adult tapeworms collected from Cheju inhabitants after treatment with bithionol (Table 2). Lee et al. (1966) observed *T. saginata* comprised 73.1% of adults among 26 taeniasis patients in Chollabuk-do; Cho et al. (1967), 86.7% of 105; Rim et al. (1980), 55.8% of 199 in Seoul, Chungchongbuk-do, Kyongsangnam-do and Cheju-do; Joo et al. (1985), 73.8% of 84 in Seoul and Cheju-do; and Hong et al. (1983), 100% of 26 of Sorokdo (Island, a leprosarium), Chollanam-do. Summarizing the data during the past 25 years makes it clear that *T. saginata* is

Table 2. Collective data on species ratios of *Taenia solium* and *T. saginata* from different areas in Korea with differential diagnosis by identification of scoleces or by counting the uterine branches in the gravid proglottids (1965-1988)

Authors	Years	Localities	No. of exam.	*T. solium* No. (%)	*T. saginata* No. (%)	Unidentified[a] No. (%)
Kang et al.	1965	Cheju-do	376	27 (7.1)	327 (86.9)	22 (6.0)
Lee et al.	1966	Chollabuk-do	26	7 (26.9)	19 (73.1)	0 (0)
Cho et al.	1967	Cheju-do	105	11 (10.5)	91 (86.7)	3 (2.9)
Rim et al.	1980	Seoul	151	59 (39.1)	82 (54.3)	10 (6.6)
		Chungchongbuk-do	10	0 (0)	7 (70.0)	3 (0.0)
		Kyongsangnam-do	30	12 (40.0)	16 (53.3)	2 (6.7)
		Cheju-do	8	2 (25.0)	6 (75.0)	0 (0)
Hong et al.	1983	Sorokdo Island	26	0 (0)	26 (100.0)	0 (0)
Joo et al.	1985	Seoul	13	4 (30.8)	9 (69.2)	0 (0)
		Cheju-do	71	13 (18.3)	53 (74.6)	5 (7.0)
Soh et al.	1988	Cheju-do	58	0 (0)	58 (100.0)	0 (0)
Total			874	135 (15.4)	694 (79.4)	45 (5.1)

[a]Most unidentified cases were caused by omitting collection of the evacuated worms from patients.

dominant by an average of 79.4% (53.3-100.0%) over *T. solium* (15.4%) among Korean people, which makes the approximate ratio of 1 : 5 for *T. solium* and *T. saginata* (Table 2).

Records on larval *Taenia* tapeworms in intermediate hosts

Most of the reports on the metacestode surveys in intermediate hosts for *Taenia* tapeworms are on the Cysticercus cellulosae in pigs in Korea (Inoba, 1924; Kim, 1984a, 1984b; Kim, 1985; Jang and Kang, 1989). On the other hand, only limited reports are available for C. bovis, the larval tapeworm of *T. saginata*, from cattle. Inoba (1924) reported prevalences of 17.8-21.3% among 731 cattle in Seoul and Kongju. Nakanishi (1926) reported 37.6% of C. bovis positive cases in 408 Korean native calves from all over the country. Additionally, prevalences of 37.1% (56/151) were reported in Kyongju, 61.1% (22/36) in Masan, 14.6% (3/22) in Kimhae, 40.1% (8/20) in Ulsan, 40.0% (4/10) in Milyang, 0% (0/2) in Chongju, 42.9% (3/7) in Sariwon, 28.6% (2/7) in Chongdo, 100.00% (3/3) in Taegu, 40.0% (2/5) in Namhae 50.0% (2/4) in Tongnae, 0% (0/1) in Kojedo, and 34.8% (48/138) of C. bovis from areas of southern Korea. Most of the calves (62.1%), in the report, revealed light infections with under 10 metacestodes per calf; however, more than 100 were also found in some calves (2.6%), with a maximum infection of 10,462 in one calf. Infective organs were the heart, striated muscle, tongue, masseter muscle, diaphragm, lung, subcutaneous tissue, omentum, serosa, scrotum and stomach wall as well as a few cases from lymph nodes, esophagus, liver, kidney, pancreas, bladder, thymus, intestinal wall, testicles, epididymis, spleen, breast, uterus, ovary, spinal cord and eyes. Another paper by Isshiki (1960) reported retrospectively 30.9% of metacestodes from cattle back to 1936, and 5.1% back to 1943 in Cheju-do. Most recently, there was at least one local episode of measled cattle in Kongkun-myon, Hoengsong-Gun, Kangwon-do in November, 1975. The inhabitant who found the measled beef could not eat it, and should have discarded it (personal communication with Dr. Seung-Yull Cho in 1990).

All these data reveal that larval *T. saginata* tapeworms in cattle was common in Korea.

Eating habits reveal an inconsistency with the species ratio of tapeworms

Since the 1960s, substantial epidemiological studies on *Taenia* tapeworm infections were performed in Cheju-do, Chollabuk-do or other provinces; and for more than 30 years thereafter, most of the researchers repeatedly felt that the textbooks do not coincide well

Table 3. Interviews on the habit of eating raw pork, pig's viscera and raw beef of inhabitants in Cheju-do (1963-1982)

		Pigs						Cattle		
Authors	Years	Intrv[a]	Pork	%	Intrv	Viscera	%	Intrv	Beef	%
Park and Chyu	1963	463	97	21.0	463	242	52.3	ND[b]	ND	ND
Kang et al.	1965a	8,161	353	4.3	5,286	1,017	19.2	8,223	266	3.2
Cho et al.	1967	473	121	25.6	473	176	37.2	473	74	15.7
Kim	1977	1,010	165	16.3	ND	ND	ND	1,010	204	20.2
Kim	1980	1,304	122	9.4	652	209	32.1	1,304	153	11.7
Kim	1982	1,066	32	3.0	956	310	32.4	1,066	39	4.0
Total		12,477	890	7.1	7,830	1,954	25.0	12,076	736	6.1

[a]Number of interviewees, [b]Not done.

with the tapeworm life cycles in Korea. Most of the epidemiological studies on consumption of foods showed continual inconsistency with the species ratio of *Taenia* tapeworms. Especially on the occasions of special ceremonies like weddings, funerals and meetings, the residents in rural villages used to slaughter the pigs by themselves; which is known as 'Churyum'. Eating the raw liver is the most favorite (96.7%) habit, and other organs, like the apex of the spleen, lungs, kidneys, pancreas and tongue are eaten preferably raw. In those villages, however, eating the raw beef is rare (Park and Chyu, 1963). Cho et al. (1967) suggested that *T. saginata* infected people more frequently even though they ate the raw pork (25.6%) or the raw liver of pigs (37.2%) more frequently than eating the raw beef (15.7%) or raw liver of cattle (11.4%) among 2,104 subjects in Cheju. Kim (1980) reported that most of the rural people with taeniasis in Cheju-do ate raw liver of pigs and cattle. Kim (1982), in a survey on the habit of eating raw foods and parasite infections, found the majority of people (32.6%) ate the raw liver of pigs.

Summing up the ratio of pork-eaters versus beef-eaters, it was approximately 1:1 (7.1% : 6.1%) out of 12,477 individuals subjected to questionnaire surveys. Additionally, those who consume pig viscera may reach as high as 25.0% of the population in Korea. Therefore the data can be analysed as pig-eaters versus cattle-eaters, in other words, pork plus viscera eaters of pigs versus beef-eaters, (7.1 + 25.0) : 6.1 = 32.1 : 6.1 (approximately 5:1), as seen in Table 3.

A more specific breakdown of Korean eating habits for the visceral organ of pigs, among 7,357 respondents, were: liver 24.0%, intestine 5.4%, lung 0.8% and spleen 0.7%. Of these, average 10.2% (10.1-11.4) were also liver-eaters of cattle (Kang et al., 1965a; Cho et al., 1967).

Between 1992 and 1995, a survey on the eating of the raw liver of pigs and cattle, covering eight provinces in South Korea, revealed that an average of 18.7% (1,349/7,211) of Koreans had experiences of eating raw liver of pigs; and 19.8% (1,425/7,211) for eating cattle liver. The report also determined that Cheju inhabitants (27.2%) eat more raw pig liver than those of any other province (Fig. 1). Some of the pig's livers were obtained from neighbors, pubs or meat shops, but most (80%) were obtained by slaughtering pigs on their own. Twenty-two percent of subjects had experienced eating raw pig liver more than 11 times. Most of the cattle's livers, in contrast, were purchased from meat shops (42%) as well as from pubs, neighbors or department stores. The percentage of people who had experienced eating raw liver of cattle more than 11 times was 25% (Eom, 1995).

These collective data give us a clear understanding on the inconsistency between food consumption patterns and the prevalence of *T. saginata*. The still unchanged habits for eating the raw liver of pigs and cattle in the 1990s Korea is noteworthy.

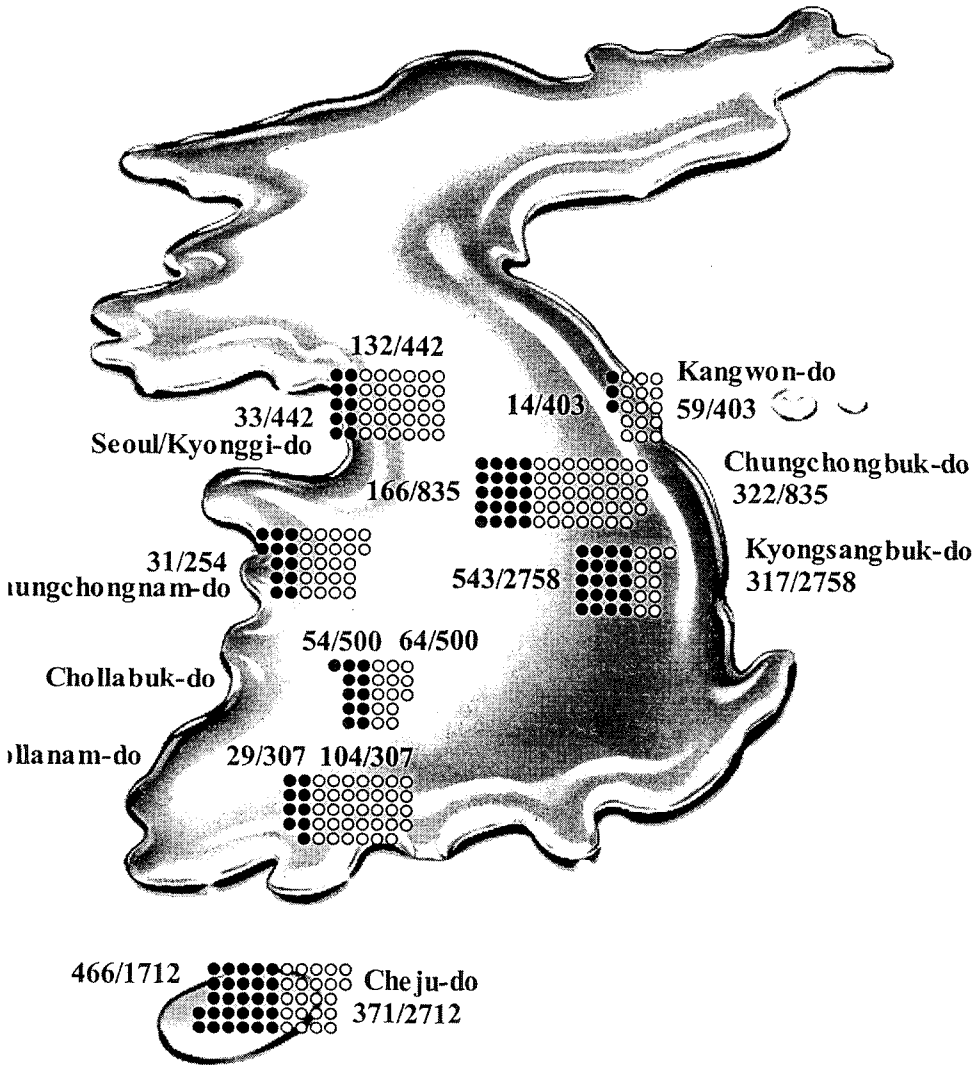

Fig. 1. Eating habit of raw liver of pigs (●) or cattle (○) by interview in eight surveyed provinces in Korea (1992-1995). The overall positive cases eating raw liver of pigs or cattle out of 7,211 subjects were 18.7% and 19.8%, respectively. Open or closed circles represent 1% each.

Enigmatic Sorokdo Island showing clear inconsistency

Obviously the most distinct puzzle, recognized by Hong et al. (1983), was in Sorokdo Island, at a leprosarium, where there were no cattle, although many *T. saginata*-like tapeworm occured among inhabitants; and only pigs were reared. Considering that the small island is isolated from the peninsula, it is difficult to understand what led the authors to speculate that the worms might be transfered from other provinces, or from land.

TAENIA ASIATICA, A CLUE TO EPIDEMIOLOGICAL UNDERSTANDING

What is *Taenia asiatica*?

Asian *Taenia* was first identified in Taiwan aborigines, soon after it has been also found to be distributed in many Asian countries including Korea, Indonesia, the Philippines and Thailand (Fan et al., 1988, 1989a, 1989b; Zarlenga et al., 1991; Bowles and MacManus, 1994; Fan and Chung, 1998).

Historically, Huang et al. (1966) first refused to refer to the Taiwan *Taenia* as *T. saginata* because it didn't seem to come to human through beef, as most textbooks indicate. Consequently, Chao et al. (1979) observed that the eggs of Taiwan *Taenia* could infect the liver of pigs, but not the muscle of cattle. Consequently Chung et al. (1987) found that wild boars and Lanyu pigs were intermediate hosts in Taiwan. Eom and Rim (1992a, 1992b) in Korea also observed that this special tapeworm caused human taeniasis through the eating of the raw pig liver. The natural infection rate was revealed to be 1.01% in Korean domestic pigs (Eom and Rim, 1992a). Further more, Eom et al. (1992) observed that the Asian *Taenia* metacestodes caused viscerotropic cysticercosis experimentally in new internal organs of pigs, such as the omentum, lung and serosa, as well as in an organ already known to be infected, the liver. Eom and Rim (1993) proposed a new species for this worm, *Taenia asiatica*, with the following taxonomic evidence: *T. asiatica* has a rostellum without hooklets, and this feature discriminates it from the classical *T. saginata*, along with some other morphological characteristics, such as the large number of uterine twigs, and the posterior protuberance of gravid proglottids. *T. asiatica* metacestodes (Cysticercus viscerotropica) also differ morphologically from *T. saginata* metacestodes (C. bovis) in having wart-like formations on the external surface of the bladder wall (Eom and Rim, 1993).

Traditionally the armed *T. solium* Linnaeus (1758) and the unarmed *T. saginata* Goeze (1782) were classified on the basis of the presence or absence of the hooklets (arm) and the rostellum on the scolex. The armed tapeworm, *T. solium*, has both of these structures. *T. asiatica*, on the other hand, looks phenotypically similar to classical *T. saginata*, which provoked debates on the taxonomic status at the level of species or subspecies.

Taxonomic disagreement on this tapeworm induced a redescription of Fan et al. (1995), where it was considered as a subspecies, *T. saginata asiatica*, on the basis of morphological similarities. Molecular methodologies were applied to this debate by comparing nucleotide sequences of the mitochondrial cytochrome C oxidase I (COI) and 5' 28S rDNA, and exhibited an intimate relationship of the *Taenia* species or subspecies, which supported the insistence of subspecies (Bowles and McManus, 1994; Fan and Chung, 1998).

Further studies on the morphology and genotype demonstrated that this parasite should be considered a distinct species, which is closely related to *T. saginata* and more distantly so to *T. solium* (Zarlenga and George, 1995; Galan-Puchades and Mas-Coma, 1996; Galan-Puchades and Fuentes, 2000; Hoberg et al 2000; Schantz, 2000).

Classical *T. saginata* infects humans through beef, and *T. solium* through pork, but *T. asiatica* through the viscera of pigs; in other words, the life cycles are different (Fig. 2).

Natural infections of Cysticercus viscerotropica in Korean domestic pigs

The natural infection status of *T. asiatica* metacestodes (C. viscerotropica) was reported by Eom and Rim (1992a) from the liver of pigs inspected in Chongju, Chungchongbuk-do, Korea. All pigs were six months old cross-bred pigs of Yorkshire, Landrace, Duroc or Hampshire breeds. Live metacestodes were found in only 0.01% (3/25,358) of the examined livers, and were distributed randomly in lobes of livers (Fig. 3). The liver Livers were infected with one to ninety-six metacestodes. Most of the metacestodes, however, were either calcified (87.1%) or highly degenerated (12.9%). When metacestodes were alive, host tissue capsules were transparent. The capsule with degenerated metacestodes contained pus cells or mucopurulent fluid in the space between the thick yellowish host tissue capsule and the non-motile bladder worm.

If we postulate that Asian tapeworm metacestodes develop from eggs in 1 month, the metacestodes recognized in the liver had been infected for 1 to 5 months. In this short period of infection, all but a very few died. This is not a common feature in metacestodes of either *T. solium* or *T. saginata*, which live in the muscle of pigs or cattle for longer than a year. Even if very few *T. asiatica* metacestodes

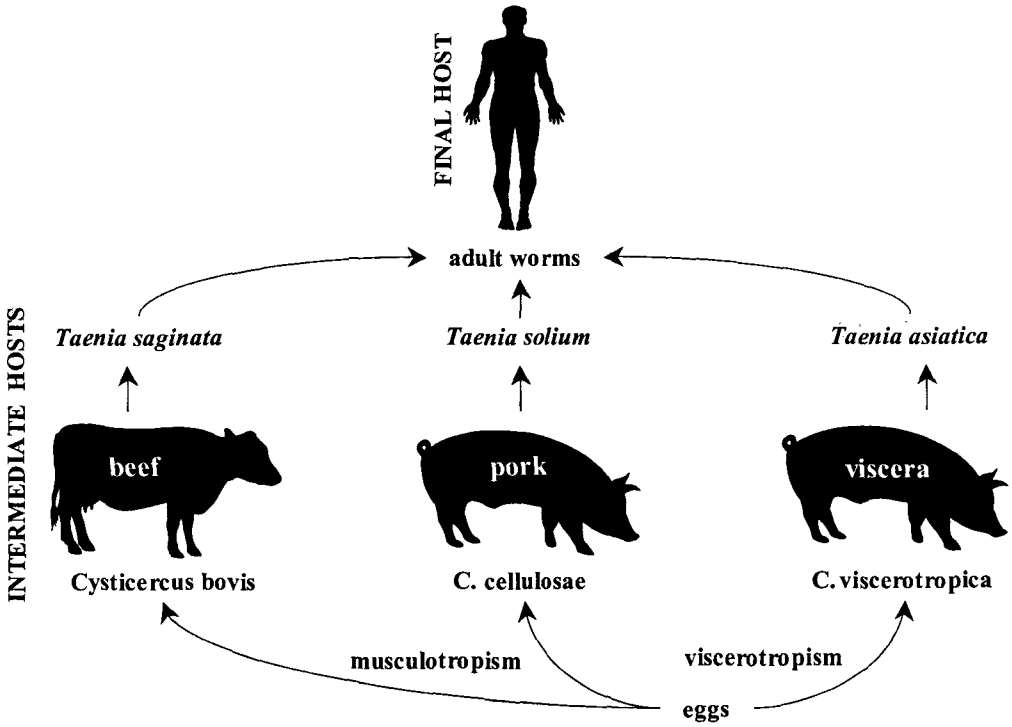

Fig. 2. Life cycles of three human *Taenia* tapeworms showing different organotropism, viscerotropism for *T. asiatica* and musculotropism for *T. saginata* or *T. solium*, in intermediate hosts.

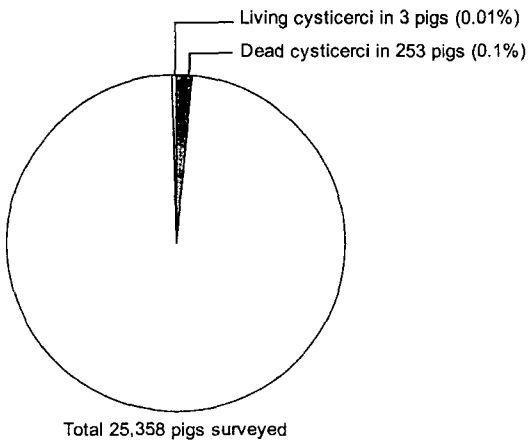

Fig. 3. Natural infection status of *Taenia asiatica* metacestodes, living or dead, in the livers of 25,358 pigs slaughtered at an abattoir in Chongju, Korea (Eom and Rim, 1992a).

are alive in the liver, and the liver can still be a source of human infection. Chances of human infection should be very low, if any. This fact of rapid death of *T. asiatica* metacestodes in the livers of the pigs raises the question that there may be other tissues where *T. asiatica* metacestodes maintain patent infection for a longer period.

Experimental infections in a human volunteer, pigs and cattle

The infectivity of metacestodes of *T. asiatica* in human hosts was confirmed in a volunteer (Eom and Rim, 1992b). The metacestodes used in the experimental infection were collected from the livers of naturally infected domestic pigs at an abattoir in Chongju City (Eom and Rim, 1992a). The scolex, recovered after treatment, was found to be unarmed. The number of main uterine branches, varying from 16 to 21, was similar to that of *T. saginata*. With the eggs of *T. asiatica* from the experimentally infected Korean volunteer, the authors infected and observed the infection sites of the metacestodes in the visceral organs of pigs and cattle.

In the experimental study in pigs, *T. asiatica*

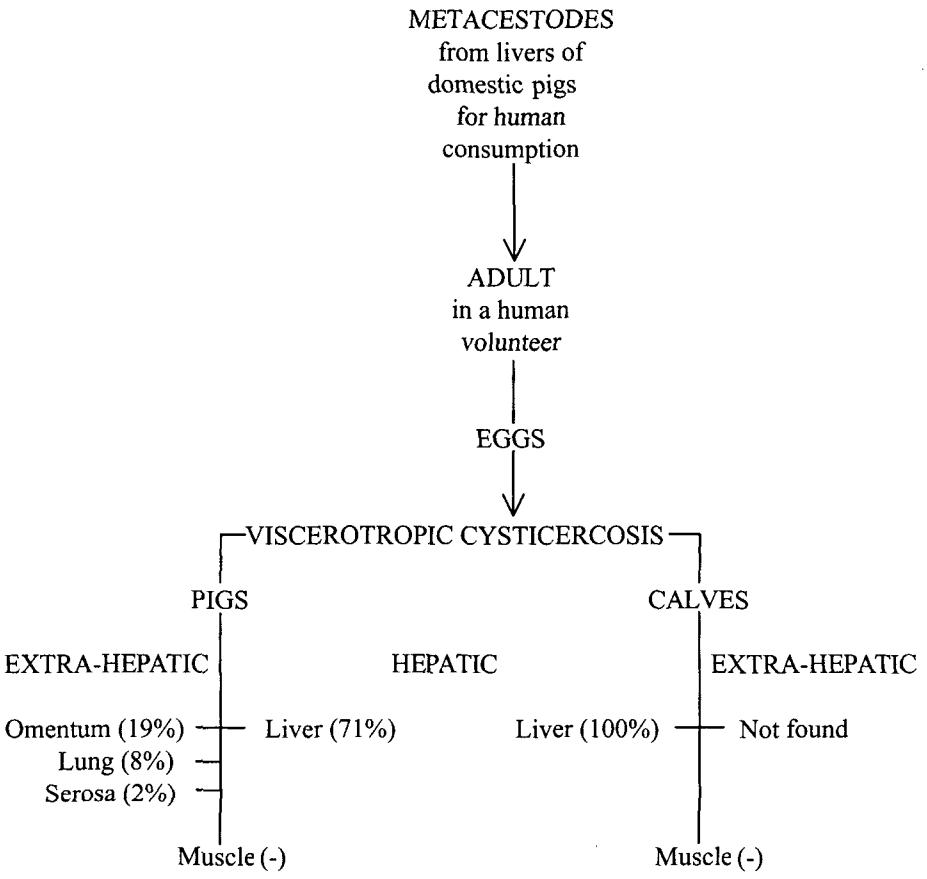

Fig. 4. Hepatic or extrahepatic distributions of Cysticercus viscerotropica in pigs and calves experimentally infected with the *Taenia asiatica* eggs collected from an experimentally infected human volunteer. Viscerotropic cysticerci do not affect muscles, but affect visceral organs of intermediate hosts.

eggs infected both of the hepatic and extrahepatic organs of pigs. Viscerotropic cysticercosis was observed in the pigs, with a majority of the non-calcified metacestodes in the livers (hepatic) and a minority in other organs (extrahepatic) such as the omentum, the lung and the serosa. Living metacestodes were observed both in hepatic and extrahèpatic infection (Fig. 4).

In the experimental study using cattle, *T. asiatica* eggs infected calves in their livers but all were found to be calcified, measuring diameter less than 1.5 mm. *T. saginata* eggs infected calves in the muscle only (Fig. 4).

T. asiatica versus *T. saginata* in Korea

There is no doubt that Korea is one of the endemic areas for *T. saginata*, recalling the reports on C. bovis between the years 1924 and 1943 from calves in Cheju and many other provinces, with infection rates revealed to be 5.1-37.6% in cattle. The most recent observation appears to be in the measled cattle which was discarded by villagers in Kongkun-myon, Hoengsong-gun, Kangwon-do in 1975; this anecdote was reported to a Korean parasitologist. Considering all of the previous evidence, as well as the Korean habit of eating raw beef, and that no parasitologists living today had ever seen larval tapeworms in cattle by themselves, it is not difficult to speculate that Korea has had classical *T. saginata* in the past. But the recent researches by morphological or molecular biological methods after 1993 reveal that most of the tapeworms found are *T. asiatica*, and not *T. saginata*.

This situation leads to curiosity about the presence of *T. saginata* in recent times. Even if it is possible to find *T. asiatica* among the old slide specimens, labeled as *T. saginata*, preserved in many parasitology laboratories in universities and institutes scattered in Korea, the differential diagnosis is not easy, due to the morphological similarities between *T. asiatica* and *T. saginata*. An alternative method of identification, with the use of recently developed molecular biological methods, also has limited application due to DNA damage by long-term preservation of the worms in formalin.

More recently, Eom et al. (2000) reported a *T. saginata* case collected from a local hospital in Pusan. The *Taenia* worm from the case was transfered to and analysed in the Department of Parasitology, Chungbuk National University School of Medicine. The two terminal proglottids transfered did not show posterior protuberances, which are one of the differential diagnostic characters. One of them was 9 by 4 mm and the other was 11 by 4 mm, in measurements of terminal proglottids. The numbers of uterine main branches were not countable, because most of the eggs were discharged out of the uterus. Random amplified polymorphic DNA-polymerase chain reaction was done on isolated genomic DNA, which showed main bands in 1.95, 1.59, 1.00, 0.80 and 0.66 kb with a primer, oligonucleotides A-08 5′-GTG ACG TAG G-3′; and multiple bands of 2.07, 1.82, 1.59, 1.13 and 0.86 kb with another primer, A-20 5′-GTT GCG ATC C-3′. These bands were identical with *T. saginata* from Poland and Belgium but were different from *T. solium* originating from Honduras and China, as well as from *T. asiatica* from many countries.

This subject, a Korean woman aged 46-years, had no experience of eating raw liver of pigs, but prefered raw beef without any experience of traveling to other countries a few years before and after observing the expulsion of terminal proglottids by herself. With overall consideration of these data, *T. saginata* thus is distributed sympatrically with *T. asiatica* in Korea.

UNRAVELING THE EPIDEMIOLOGICAL INCONSISTENCY WITH REFERENCE TO *T. ASIATICA*

Hypothesis 1 with reference to pig's viscera

Natural infection of *T. asiatica* metacestodes in Korean domestic pigs was reported in 1992 by Eom and Rim. The infectivity of those metacestodes was also confirmed in a human volunteer (Eom and Rim, 1992). If we assume the visceral organ of pigs as a source of *Taenia* tapeworm infection, we can now explain the epidemiological inconsistency as follows. The species ratio of 'armed tapeworm versus unarmed tapeworm = 15.4 : 79.4 = 16 : 84' and fits well to 'the food-consuming ratio of pork versus pig's viscera plus beef = 7.1 : (25.0 + 6.1) = 7.1 : 31.1 = 19 : 81' (Table 2 & 3; Fig. 5). Or being more simple, armed tapeworm versus unarmed tapeworm is 16 : 84 = (approximately) 1 : 5. And pork versus pig's viscera versus beef is 7.1 : 25.0 : 6.1 = (approximately) 1 : 4 : 1. In other words, pork : (pig's viscera + beef) is 1 : (4 + 1) = 1 : 5. Conversely, the 5 : 1 ratio of pig-eaters versus cattle-eaters can be explained as follows. Pig-eaters consist of pork-eaters and viscera-eaters, and cattle-eaters consist only of beef-eaters, which makes (1 + 4) : 1 = 5 : 1. This figuring can be shown with simple numbers in brackets in Fig. 5. Again, the pig's viscera plays an important role in the transmission of *T. asiatica*, with a relative ratio value, 4, which unravels the inconsistency between 1 : 5 and 5 : 1. Here we can now understand that pigs play their role both as an infective source of *T. solium* with pork, and *T. asiatica* with visceral organs. This hypothesis gives a definite role of the pig's viscera in the tapeworm epidemiology in Korea (Table 3).

Hypothesis 2 with reference to cattle's liver

Still no natural evidence of live C. viscerotropica in the liver of cattle is available. It needs further evaluation yet, but 10.2% (10.1-11.4) of people eat raw liver of cattle (Kang et al., 1965a; Cho et al., 1967) and this may receive due consideration for its importance in *T. asiatica* epidemiology in future, because human infection is possible

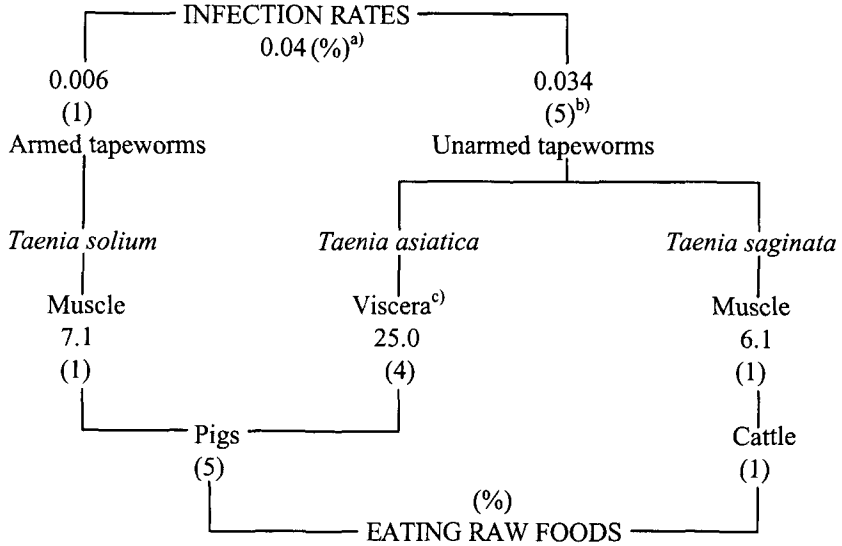

Fig. 5. Comparison of ratios between species and food consumed. Approximate numbers are shown in the brackets. In this hypothesis, pig's viscera plays an important role in the transmission of *T. asiatica*, with a relative ratio of 4, which unravels the inconsistency between 1 : 5 and 5 : 1. a)Data obtained from the egg positives based on the Table 1 by averaging prevalences during 1990-1999. b)Proportion of species was based on the ratio summarized in Table 2. c)Viscera consumed consists of the liver, intestine, lung and spleen with the proportion obtained from data summarized in Tables 3.

with live metacestodes recovered from the liver of experimental cattle in Taiwan (Chao et al., 1988). This hypothesis gives a good fit between the species ratio of armed tapeworm versus unarmed tapeworm, at 16 : 84, and the eating habits, i.e., pork : pig's viscera plus cattle's liver plus beef was 7.1 : (25.0 + 10.2 + 6.1) = 7.1 : 41.3 = 15 : 85, theoretically though, if we assume that transmission rates to humans are equal for the three different species.

Taenia tapeworm infections among humans correspond closely to the eating habits of intermediate hosts in each country. In Korea, we can count the eating habits of 'Churyum' and 'Semmai' those rationalize our hypothesis 1 and 2. 'Churyum' is one of Korean habits of eating widely spread among rural people in Cheju or other provinces where they eat raw liver of pigs while they are still warm right after slaughtering during village ceremonies. The other term, 'Semmai' is also called 'Senmai' which means [Senezi (n) n. Fat around the intestines; epiploon, fatty skin around the intestine of animals, fat of the epiploon; thin layer of fatty tissue on the cud pouch or rumen, semeze = semezi (provided by Prof. Won-Kil Park, Academic Society of Korea and Mongolia)]. The terms implicate the possible source of *T. asiatica* infection by eating 'Semmai', the fat, contaminated with extrahepatic metacestodes that could be introduced to human and cause tapeworm infections. In other words, this Mongolian term has been used in Korea, especially in Cheju-do, since the 13th century when Mongolian soldiers temporarily ruled. The habit of eating raw *Semmai* alone or attached to the stomach, spleen or any other visceral organs may cause the infection with *T. asiatica*. The omentum and fat tissue around the stomach, spleen and intestine harbor sometimes many hidden, hardly recognizable, transparent metacestodes. Eating the raw spleen itself may have no meaning but eating the omentum or fat tissues around the organs together with fat may induce the tapeworm infection. We can say the same is true for the other visceral organs such as the stomach, intestine, kidney and pancreas.

Of the three tapeworms in Korea, the distribution ratio is uncertain now, but it may be possible to speculate a ratio of *T. solium* : *T.*

asiatica : *T. saginata* is about 7.1 : 25.0 : 6.1 = 19 : 65 : 16 (approximately 1 : 4 : 1) according to hypothesis-1; or 7.1 : (25.0 + 10.2) : 6.1 = 15 : 73 : 13 (approximately 1 : 5 : 1) according to hypothesis-2.

Evaluating the application of these hypotheses, we can get a clear understanding about the epidemiologicalal enigma, which was addressed continuously since the 1960s in Korea, by simply acknowledging the existence of *T. asiatica*.

Comparative epidemiologicalal patterns in Korea and other Asian countries

The custom of eating raw viscera is not new in other Asian countries also, like Taiwan and Thailand where Asian tapeworm is endemic (Cross et al., 1991; Fan et al., 1989b). Usually the small intestine and the flesh of wild or domestic animals are eaten raw in these countries, and most Asian countries are believed to have a similar kind of Asian tapeworm phenomenon as in Korea.

An isolated island Sorokdo (a leprosarium) is a small place showing the most simple pattern

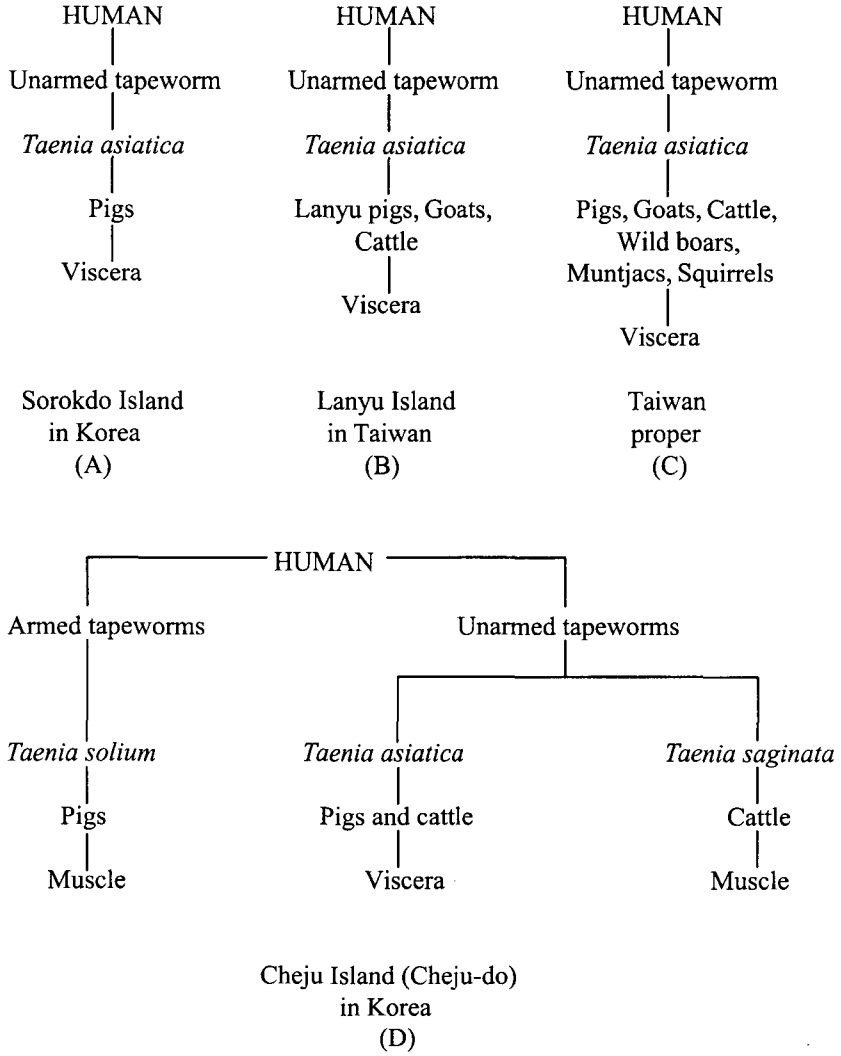

Fig. 6. Comparative epidemiologic patterns of *Taenia* tapeworms in Korea and Taiwan with host ranges. Complexity of *Taenia* epidemiology can be rearranged as Sorokdo Island < Lanyu Island < Mainland Taiwan < Cheju Island.

of *Taenia* epidemiology in Korea, and possibly, in the world. This unique place of leprosy patients' residence has a single kind of *Taenia* tapeworm with a single kind of intermediate host, pig. So distinct was this epidemiological pattern with unarmed *Taenia* tapeworm, the pig was suspected to be an intermediate host of this tapeworm, and *T. asiatica* was identified later, without difficulty in retrospective, though; this place is considered to be the most simple place in this study (Fig. 6A).

The most similar Taiwanese place to Korean Sorokdo Island is Lanyu Island, of 30 square miles. As is known to western hemisphere with a familiar name, Orchid Island is a land of the Yami tribe, who moved to this small island two hundred years ago from South-East Asia, via the Philippines. Since 1960 when Hsieh first reported a beef tapeworm, it was known as one of the endemic areas of *T. saginata*. Quite recently, however, it was recognized as Asian *Taenia*, which was transfered to humans through Lanyu native pigs, a confirmed intermediate host (Chung et al., 1987). It is a simpler place, with wild animals and native goats, than mainland Taiwan; but it shows a rather more complicated epidemiological pattern than Korean Sorokdo Island, because it has cattle, the intermediate host of beef tapeworm (Fig. 6B).

In contrast, the mainland Taiwan is an island far bigger than either Sorokdo Island or Orchid Island, with many intermediate hosts as well as with complicated eating habits of raw foods. In Taiwan, *Taenia* tapeworms are prevalent as high as 17% and all of the tapeworms are unarmed, and thus *T. solium* is not available (Liu et al., 1981; Chan et al., 1987; Chung et al., 1987; Chung et al., 1988; Lin et al., 1988; Fan et al., 1989a, 1989b). It shows a more complicated epidemiological pattern than on Lanyu Island, in having many kinds of possible intermediate hosts as well as with complicated eating habits of raw foods; but there is no *T. solium* (Fig. 6C).

It is strongly considered that the pork tapeworms and the beef tapeworms occur together in Korea where the pigs and cattle are also distributed, and as well, both of them are eaten raw. Considering this epidemiologicalal complexity, it must have been difficult for parasitologists to determine what kinds of tapeworms are transfered through what kinds of intermediate hosts. As for the reason for more beef tapeworm infections, the suggestion that raw beef was consumed more frequently was not persuasive at all, because of the rarity of *T. saginata* metacestodes in intermediate hosts. Evidently, this erroneous speculation was closely related to the presence of *T. asiatica* that shares the pigs as intermediate hosts with *T. solium*; Cheju-do Island had been a very complex place to understand.

We can rearrange from the simplest to the hardest aspect of environmental complexity in understanding *Taenia* epidemiology as follows: Sorokdo Island < Lanyu Island < Mainland Taiwan < Cheju-do Island (Fig. 6A, B, C & D). It may sound paradoxical, but Cheju-do is one of the best places to study because it is separated from the land, has a small area, but has all complex factors on *Taenia* epidemiology just as in other Asian countries which have a similar infection pattern to Korea.

Thus the explanation for the epidemiological inconsistency, which may possibly occur in other Asian countries also, is likely to depend on recognition of the unarmed tapeworm, *T. asiatica*.

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