Brief morphological description of stichotrichid ciliates (Ciliophora: Stichotrichia) from Korea

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**INTRODUCTION**

The class Spirotrichea is one of the most species-rich group of the Ciliophora Doflein (1901) (Lynn, 2008). To resolve taxonomic ambiguities among spirotrich members, their relationships have been revised on the basis of traditional and molecular phylogenetic analyses. Of seven spirotrich subclasses, the Stichotrichia Small & Lynn, 1985 is especially difficult to study due to its high diversity and unresolved taxonomy (Schmidt *et al.*, 2007; Lynn, 2008). Although stichotrichs are one of the most heavily researched ciliate groups in Korea, about one third of Korean reported, many unrecorded species are still waiting to be discovered (Dovgal and Pešić, 2014; Jung *et al.*, 2017a; 2017b; 2017c; Park *et al.*, 2017; Choi *et al.*, 2018; Kim and Jung, 2018).

In the present study, we provide a brief diagnosis and remarks of 10 ciliate species belonging to the subclass Stichotrichia previously unrecorded in Korea. The ciliates were identified based on the observation of both live and stained specimens.

**MATERIALS AND METHODS**

For soil samples, we used the non-flooded Petri dish culture method (Foissner *et al.*, 2002). Freshwater and seawater samples were filtered with 200 μm nylon mesh and then were transferred to Petri dishes with rice or wheat grains to enrich growth of bacteria and bacterivorous flagellates recognized as a food source for ciliates. All samples were cultured at 18-20°C.

For species identifications, Protargol impregnation was performed according to Foissner (2004). Living and stained specimens were observed under a stereo microscope (SZH10; Olympus, Tokyo, Japan) and a light microscope (DM2500; Leica, Wetzlar, Germany) at magnifications ranging from 50× to 1,000×. Classification and terminology follow Berger (2006), Foissner (2016), Kumar and Foissner (2015), and Huang *et al.* (2014).

**RESULTS AND DISCUSSION**

Phylum Ciliophora Doflein, 1901
Class Spirotrichea Bütschli, 1889
Order Urostylida Jankowski, 1979
Family Urostylidae Bütschli, 1889
Genus *Parabirojimia* Hu *et al.*, 2002

1. *Parabirojimia similis* Hu *et al.*, 2002 (Fig. 1)
Material examined. Seawater (32‰) from Oho breakwater, Gangwon Province, Korea (38°19'33"N, 128°31'47"E), on June 2018.

Diagnosis. Cell size 130-155 × 40-55 μm in protargol preparations, body outline roughly elongated elliptical, widest in anterior body third, left and right margin converging posteriorly, and flexible; adoral zone 25% of body length, 37-54 adoral membranelles, bipartite; 4 or 5 macronuclear nodules with about 3 micronuclei; 3 frontal and 2 frontoterminal cirri; 1 buccal cirrus; 5-7 cirri in midventral pairs with 37-48 additional midventral cirri; 5-8 transverse cirri; 1 left and 5 or 6 right marginal cirral rows; 3 dorsal kineties; caudal cirri lacking.

Remarks. Two described *Parabirojimia* species, *P. multinucleata* and *P. similis*, are different by the following combination of features: numbers of macronuclear nodules (43-70 vs. 3-6), right marginal cirral rows (invariably 5 vs. 5-8), ventral cirri (44-69 vs. 27-45), and adoral membranelles (52.4 vs. 46.7 on average) (Chen et al., 2010). The Korean population of *P. similis* corresponds very well with the Chinese population (Berger, 2006).

Deposition. Four slides (NIBRPR0000109455-NIBRPR0000109458) have been deposited at the National Institute of Biological Resources (NIBR), Korea.

Genus *Arcuseries* Huang et al., 2014

2. *Arcuseries warreni* (Song & Wilbert, 1997)

Huang et al., 2014 (Fig. 2)

Material examined. Seawater (28.8 ‰) from Incheon Port, Korea (37°26’57”N, 126°35’37”E), on May 2018.

Diagnosis. Cell size 65-80 × 25-30 μm in protargol preparations, oval shape, and flexible; adoral zone 32% of body length, 28-30 adoral membranelles; 43-60 macronuclear nodules; conspicuous cortical granules arranged around dorsal bristles, erythrocyte-like granules densely distributed in cytoplasm; 3 frontal and 2 frontoterminal cirri; 1 buccal cirrus; 7-12 transverse cirri and 2 pretransverse ventral cirri; 1 left (20-25 cirri) and 1 right (20-27 cirri) marginal cirral row; 3 dorsal kineties; hair-like ejected granules present; caudal cirri lacking.

Remarks. *Arcuseries warreni* can be easily distinguished from other *Arcuseries* species by conspicuous erythrocyte-like granules and hair-like ejected granules. In the Korean population of *A. warreni*, cortical granules were mainly arranged along with cirri, and around dorsal bristles (Fig 2B, C).

Deposition. Two slides (NIBRPR0000109459, NIBRPR0000109450) have been deposited at the National Institute of Biological Resources (NIBR), South Korea.

Order Sporadotrichida Fauré-Fremiet, 1961
Family Gonostomatidae Small & Lynn, 1985
Genus *Gonostomum* Sterki, 1878
3. **Gonostomum lajacola** Foissner, 2016 (Fig. 3)

**Material examined.** Soil sample from Wangsan-ri, Jung-gu, Incheon, Korea (37°26′47″N, 126°23′40″E), on February 2018.

**Diagnosis.** Cell size 70-95 × 25-40 μm in protargol preparations; 33-40 adoral zone of membranelles; cortical granules present, colorless; 2 macronuclear nodules with 2 or 3 micronuclei; 3 frontal cirri; 2 frontoterminal cirri; 1 buccal cirrus; 17-24 paroral; 2 or 3 frontoventral cirral pairs; 6 or 7 pretransverse and transverse cirri; 1 left (10-14 cirri) and 1 right (20-23 cirri) marginal cirral row; 3 dorsal kineties; 3 caudal cirri.

**Remarks.** *Gonostomum lajacola* is highly similar to three congeners, *G. bromelicola*, *G. fraterculus*, and *G. singii* (Foissner, 2016). *Gonostomum bromelicola* and *G. fraterculus* can be separated from *G. lajacola* by numbers of frontoventral (4 vs. 5-7), and transverse cirri (in-
variably 5 vs. 4 or 5). Furthermore, *G. bromelicola* has a distinct break in dorsal kinety 2 (vs. no break). *Gonostomum singii* differs from *G. lajacola* by cortical granules (sparse vs. dense) and the number of frontoventral cirral pairs (2 vs. variably 2 or 3) (Foissner, 2016).

**Deposition.** One slide (NNIBR2018113IV1939) has been deposited at the Nakdonggang National Institute of Biological Resources (NNIBR), Korea.

**Genus Paragonostomoides** Foissner, 2016

4. *Paragonostomoides xianicum* Wang et al., 2017 (Fig. 4)

**Material examined.** Soil sample from Gyeokpo-ri, Buan-gun, Jeollabuk Province, Korea (35°38′22″N, 126°27′59″E), on October 2015.

**Diagnosis.** Cell size 70-85 × 25-35 μm in protargol preparations; 25-28 adoral zone of membranelles; mitochondrion-like cortical granules present, colorless; 2 macronuclear nodules with about 2 micronuclei; 3 frontal cirri; 1 buccal cirrus; 3 or 4 cirri in frontoventral cirral row III; 6-8 cirri in frontoventral cirral row IV; 10 or 11 cirri in frontoventral cirral row VI; about 6 paroral; pretransverse and transverse cirri lacking; 1 left (10-12 cirri) and 1 right (16-18 cirri) marginal cirral rows; 3 dorsal kinetics; 3 caudal cirri.

**Remarks.** The Korean population of *Paragonostomoides xianicum* can be separated from *P. minutus* by body length (75 μm vs. 33 μm on average) in protargol preparations, the numbers of macronuclear nodules (2 vs. 7 or 8), left marginal cirri (10 vs. 4 on average), frontal, buccal and frontoventral cirri (15 vs. 7 on average), and basal bodies in paroral (5-8 vs. 2-3) (Kamra et al., 2008; Wang et al., 2017).

**Deposition.** Three slides (NNIBR2018113IV1940-NNIBR2018113IV1942) have been deposited at the Nakdonggang National Institute of Biological Resources (NNIBR), Korea.

**Family Oxytrichidae Ehrenberg, 1830**

**Genus Australocirrus** Blatterer & Foissner, 1988

5. *Australocirrus oscitans* Blatterer & Foissner, 1988 (Fig. 5)

**Material examined.** Soil sample from Obong-ri, Gangwon Province, Korea (38°20′11″N, 128°31′01″E), on July 2012.

**Diagnosis.** Cell size 140-185 × 90-110 μm in protargol preparations, flexible; 26-34 adoral membranelles; cortical granules lacking; 2 macronuclear nodules with about 2 micronuclei; 18 frontal-ventral-transverse cirri, 3 frontal, 1 buccal, 4 frontoventral, 3 postoral ventral, 2 pretransverse ventral, and 5 transverse cirri; 1 left (18-25 cirri) and 1 right (18-25 cirri) marginal cirral row; 8 dorsal kinetics (4 dorsal and 4 dorsomarginal kinetics); 3 caudal cirri.

**Remarks.** The genus *Australocirrus* consists of five species. Three species namely, *Australocirrus zechmeisteri-
ae, A. oscitans, and Rigidocortex octonucleatus, exhibit similar morphological characteristics. Rigidocortex octonucleatus previously belonged to the genus Australocirrus, but it was transferred to the genus Rigidocortex due to its rigid body (Berger 1999). Australocirrus zechmeisterae differs from A. oscitans and R. octonucleatus mainly by macronuclear nodules (4 in A. zechmeisterae vs. 2 in A. oscitans vs. 8 in R. octonucleatus).

**Deposition.** Two slides (NIBRPR0000104093, NIBRPR0000104094) have been deposited at the National Institute of Biological Resources (NIBR), South Korea.

Genus *Monomicrocaryon* Foissner, 2016

6. *Monomicrocaryon crassicirratum* Foissner, 2016 (Fig. 6)

**Material examined.** Soil sample from Wangsan-ri, Jung-gu, Incheon, Korea (37°26’47”N, 126°23’40”E), on February 2018.
Diagnosis. Cell size 85-100 × 40-45 μm in protargol preparations, oval shape; 24-27 adoral membranelles; cortical granules lacking; 2 macronuclear nodules, 1 micronucleus between macronuclear nodules; 18 frontal-ventral-transverse cirri, 3 frontal, 1 buccal, 4 frontoventral, 3 postoral ventral, 2 pretransverse ventral, and 5 transverse cirri; 1 left (16-19 cirri) and 1 right (16-20 cirri) marginal cirral row; 6 dorsal kineties (4 dorsal and 2 dorsomarginal kineties); 3 conspicuous caudal cirri.

Remarks. Monomicrocaryon crassicirratum can be distinguished from other Monomicrocaryon species by the following combination of features: moderate body size; conspicuous large cirri and caudal cirri; adoral zone of membranelles that occupies more than 40% of the body length; dorsal bristles that are 5-10 μm long; paroral and endoral membrane, parallel and almost straight; left pretransverse cirrus near the level of the last postoral cirrus (Fig. 6) (Foissner, 2016).

Deposition. Two slides (NNIBR2018113IV1943, NNI-BR2018113IV1944) have been deposited at the Nakdonggang National Institute of Biological Resources (NNIBR), South Korea.

7. Monomicrocaryon euglenivorum fimbricirratum Foissner, 2016 (Fig. 7)

Material examined. Soil sample from Wangsan-ri, Jung-gu, Incheon, South Korea (37°26′47″N, 126°23′40″ E), on February 2018.

Diagnosis. Cell size 55-65 × 30-35 μm in protargol preparations, shape ellipsoid; about 19 adoral membranelles; cortical granules lacking; 2 macronuclear nodules, 1 micronucleus between macronuclear nodules; 18 frontal-ventral-transverse cirri, 3 frontal, 1 buccal, 4 frontoventral, 3 postoral ventral, 2 pretransverse ventral, and 5 transverse cirri; 1 left (16-19 cirri) and 1 right (16-20 cirri) marginal cirral row; 6 dorsal kineties (4 dorsal and 2 dorsomarginal kineties); 3 conspicuous caudal cirri.

Remarks. Monomicrocaryon euglenivorum comprises two subspecies, M. euglenivorom fimbricirratum and M. euglenivorom euglenivorum. Monomicrocaryon euglenivorum fimbricirratum can be distinguished from M. euglenivorom euglenivorum as follows: body length (less than 70 μm vs. 80-90 μm); number of left marginal cirri (less than 11 vs. 15-20); transverse cirri (fringed distally vs. acicular) (Foissner, 2016).

Deposition. Three slides (NNIBR2018113IV1945-NNIBR2018113IV1947) have been deposited at the Nakdonggang National Institute of Biological Resources (NNIBR), Korea.

Genus Notohymena Blatterer & Foissner, 1988

8. Notohymena rubescens Blatterer & Foissner, 1988 (Fig. 8)

Material examined. Soil sample from Wangsan-ri, Jung-gu, Incheon, South Korea (37°26′47″N 126°23′40″ E), in February 2018.

Diagnosis. Cell size 90-105 × 35-45 μm in protargol preparations, shape ellipsoid; 27-30 adoral membranelles; cortical granules reddish color; paroral mem-
brane with hooked distal end in the typical Notohymena-pattern; 2 macronuclear nodules with 2 or 3 micronuclei; 18 frontal-ventral-transverse cirri, 3 frontal, 1 buccal, 4 frontoventral, 3 postoral ventral, 2 pretransverse ventral, and 5 transverse cirri; 1 left (18-20 cirri) and 1 right (20-22 cirri) marginal cirral row; 5 dorsal kineties; 3 caudal cirri.

**Remarks.** *Notohymena rubescens* mainly differs from other *Notohymena* species because of the reddish color of its cortical granules (*N. antarctica*, yellowish; *N. limus* and *N. pampasica*, colorless; *N. quadrinucleata*, yellowish to citrine; *N. saprai*, dark green) (Berger, 1999; Kuppers et al., 2007; Kamra and Kumar, 2010; Foissner, 2016; Naqvi et al., 2016).

**Deposition.** Three slides (NNBR2018113IV1948-NNBR2018113IV1950) have been deposited at the Nakdonggang National Institute of Biological Resources (NNIBR), Korea.

**9. Sterkiella multicirrata Li et al., 2018 (Fig. 9)**

**Material examined.** Soil sample from Bangeo-dong, Ulsan, Korea (35°28'56"N, 129°25'54"E), on November 2015.

**Diagnosis.** Body broadly elliptical, size in vivo 120-165×50-90 μm, semirigid; cortical granules lacking; 4 macronuclear nodules with about 4 micronuclei; about 50 adoral membranelles; more than 18 frontal-ventral-transverse cirri, 3 frontal, 1 buccal, 1 parabuccal, 1 IV/3, 1 or no postoral ventral, 1 or no pretransverse ventral, and 4 or 5 transverse cirri; 2 frontoventral cirral rows (FVR) (3 or 4 cirri in FVR1; 5 or 6 cirri in FVR2); 1 left (about 26 cirri) and 1 right (about 30 cirri) marginal cirral rows; 6 dorsal kineties (4 dorsal and 2 dorso-marginal kineties); 3 caudal cirri.

**Remarks.** The Korean population of *Sterkiella multicirrata* differs from its congeners by having the more than 20 frontal-ventral-transverse (FVT) cirri (vs. 17 or 18) (Chen et al., 2015; Kumar et al., 2015). The increased number of FVT cirri is a representative feature of the genus *Gastrostyla*, and the phylogenetic tree showed that *S. multicirrata* has a close relationship with the *G. steinii* group (Kumar et al., 2015; Li et al., 2018). These two genera share many morphological traits (inflexible body, lack of cortical granules, and six dorsal kineties), and only differ in the number of FTV cirri (usually 18 in *Sterkiella* vs. more than 18 in *Gastrostyla*). Based on the above mentioned findings, we supposed that the location of *S. multicirrata* is intermediated to these two genera regarding evolution.

**Deposition.** Two slides (NIBRPR0000107255, NIBRPR0000107269) have been deposited at the National Institute of Biological Resources (NIBR), Korea.

**Genus Stylonychia Ehrenberg, 1830**

**10. Stylonychia ammermanni ammermanni Gupta et al., 2001 (Fig. 10)**

**Material examined.** Freshwater taken from Danamdong, Incheon, Korea (37°33'42"N 126°43'37"E) on April 2018.

**Diagnosis.** Cell size 110-120×55-60 μm in protargol
preparations, typical shape striking bulge in region of peristome, rigid; 44-48 adoral membranelles; cortical granules lacking; 2 macronuclear nodules, 2 or 3 micronuclei; 18 frontal-ventral-transverse cirri, 3 frontal, 1 buccal, 4 frontoventral, 3 postoral ventral, 2 pretransverse ventral, and 5 transverse cirri; 1 left (14-16 cirri) and 1 right (23-25 cirri) marginal cirral row; 6 dorsal kineties, 16-20 bristles in kinety 4; 3 caudal cirri.

Remarks. The subspecies called *Stylonychia ammermanni koreana* was established by Kumar *et al.* (2016). *Stylonychia ammermanni koreana* mainly differs from *S. ammermanni ammermanni* by the following two features: number of adoral membranelles (less than 44 vs. more than 44) and number of bristles in dorsal kinety 4 (less than 15 vs. more than 16) (Kumar *et al.*, 2016). Our Korean population resembles *S. ammermanni ammer-
manni mainly due to the number of adoral membranelles (44-48) and number of bristles in kinety 4 (16-20).

Deposition. Two slides (NNIBR2018113IV1951, N NI-
BR2018113IV1952) have been deposited at the Nak-
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