

**Redescription of Three Newly Recorded *Gastrostyla* Ciliates
(Ciliophora: Spirotrichea: Stichotrichida) with
Morphological Variations from Korea**

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ABSTRACT

Three species of *Gastrostyla* ciliates collected from the sewage treatment plant and a puddle in the valley from Korea were identified as *Gastrostyla minima* Hemberger, 1985, *G. steinii* Engelmann, 1862 and *G. setifera* (Engelmann, 1862). The description was based on the observation of living specimens, protargol impregnated specimens and biometric analysis. The morphological variations among the populations of these species were investigated with morphometry. These species have not been reported in Korea and their diagnostic characteristics are as follows: *G. minima* normally has two oval macronuclei (Ma) with one spherical micronucleus (Mi) respectively, continuous ventral cirral row (VCR) with additional one postoral ventral cirrus (poVC), five transverse cirri (TC), six dorsal kineties (DK) with broken 4th kinety, and cortical granules. *G. steinii* has four oval Ma with three to five Mi, discontinuous VCR with additional one poVC, four TCs, six DKs, and no cortical granules. *G. setifera* has two oval Ma with one spherical Mi respectively, five TCs which distinctly separate in two groups, six DKs, discontinuous VCR with additional two poVCs, and no cortical granules.

Key words: *Gastrostyla*, morphological variation, morphometry, redescription, sewage treatment plant, Korea

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INTRODUCTION

The species belonging to *Gastrostyla* have diverse microhabitats in aquatic and terrestrial ecosystems. Nine species of *Gastrostyla* have been recorded up to now but no record in Korea. This genus was classified as a member of the family Oxytrichidae within the order Hypotrichida (Hemberger, 1985; Berger, 1999, 2001). Recently, it is known that *Gastrostyla* develops the ventral cirral row which is the characteristic of the family Amphiseliidae. Accordingly, it is suggested that *Gastrostyla* belongs to the family Amphiseliidae within the order Stichotrichida (Foissner, 1997; Lynn, 2002; Lynn and Small, 2000). It is not easy to establish the exact position of this genus and the more independent features are needed to resolve it. The aims of the present work are to describe the morphology and morphometry of three species of *Gastrostyla* which has never been reported from Korea.

MATERIALS AND METHODS

The present study was based on the specimens collected from the sewage treatment plant and a puddle in the valley of Munsusan Mt. in Ulsan, Korea between September, 2003 and June, 2004. The laboratory cultures were maintained in the commercial mineral water provided with dried wheat grains for supplying fungal and bacterial nutrients of ciliates and cultured at room temperature.

The shapes and movements of the living specimens were observed by DIC microscope and captured by CCD camera and photos. The infraciliature was observed by using the modified protargol method (Wilbert, 1975; Shin and Kim, 1993). The illustrations of the impregnated specimens and the living specimens were made with the aid of a camera. Biometrical analysis was performed using the method described in Sokal and Rohlf (1973). We adopted the classification schemes established by Lynn and Small (2000).

RESULTS AND DISCUSSION

Phylum Ciliophora Doflein, 1901
Class Spirotrichea Bütschli, 1889
Order Stichotrichida Fauré-Fremiet, 1961
Family Amphiseliidae Jankowski, 1979
Genus *Gastrostyla* Engelmann, 1988

1. *Gastrostyla minima* Hemberger, 1985 (Fig. 1, Table 1)

Gastrostyla minima Hemberger, 1985, p. 406, fig. 12; Foissner, 1997, p. 225, figs. 17a-m, table 12; Berger, 1999, p. 810, fig. 203e-i.

Material examined. The living specimens collected from the primary settling of Hoeya sewage treatment plant in Ulsan, Korea (129° 12'12"E and 35° 26'32"N), on 4 May 2004, were cultured

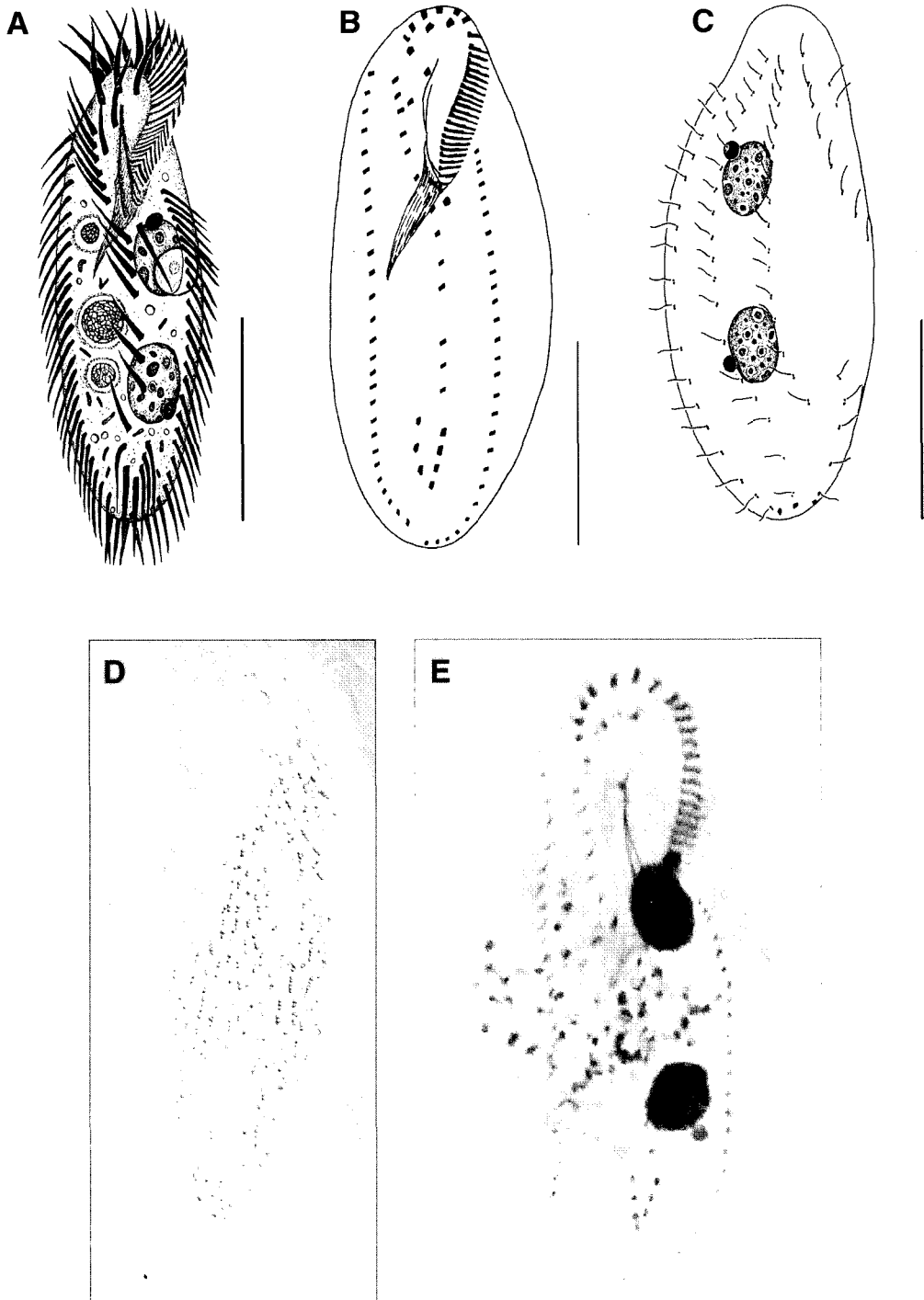


Fig. 1. *Gastrostyla minima*. A, live specimen, ventral view; B, infraciliature after protargol impregnation, ventral view; C, dorsal kineties and nuclear state, dorsal view; D, photograph of cortical granules on dorsal surface; E, photograph of protargol impregnation specimen, ventral view. All scale bars = 50 μ m.

Table 1. Biometrical characterization of *Gastrostyla minima*, *G. steinii* and *G. setifera*. All data were based on live (*in vivo*) and protargol impregnated specimens. The abbreviations in the table are the same as in the description except statistical terms (mi: *G. minima*; se: *G. setifera*; st: *G. steinii*; Med: median; Min: minimum; Max: maximum; SD: standard deviation; SE: standard error; CV: coefficient of variation in %; n: population size).

Character	Species	Mean	Med	Min	Max	SD	SE	CV	n
Body length <i>in vivo</i>	mi	138.0	143	90	155	17.0	4.0	12.0	20
	se	168.2	169	145	198	13.6	3.0	8.1	20
	st	147.0	149	125	167	13.0	3.0	9.1	20
Body width <i>in vivo</i>	mi	39.0	36	28	50	7.0	2.0	18.0	20
	se	65.7	68	48	80	9.3	2.1	14.2	20
	st	62.8	64	50	72	6.6	1.5	10.5	20
Body length/Body width <i>in vivo</i>	mi	3.6	3.4	2.6	4.8	0.6	0.1	16.5	20
	se	2.6	2.5	2.3	3.2	0.3	0.1	10.9	20
	st	2.3	2.3	2.1	2.7	0.1	0.0	6.3	20
AZM length <i>in vivo</i>	mi	41.3	41	30	50	5.0	1.0	12.0	20
	se	77.0	77	68	88	5.9	1.3	7.6	20
	st	61.5	61	50	76	7.4	1.7	12.0	20
Body length/AZM length <i>in vivo</i>	mi	3.4	3.0	3.0	4.0	0.0	0.0	13.0	20
	se	2.1	2.1	2.0	2.4	0.1	0.0	4.6	20
	st	2.4	2.3	2.1	3.1	0.3	0.1	10.6	20
AM number	mi	29.7	30	28	31	1.0	0.0	3.0	15
	se	51.0	53	30	58	6.9	1.2	13.4	34
	st	36.7	37	30	42	3.5	0.9	9.4	15
uM length	mi	29.5	30	24	33	2.5	0.6	8.5	15
	se	64.0	65	38	78	9.8	1.7	15.4	34
	st	45.9	45	38	55	5.3	1.4	11.6	15
Pharyngeal fiber length	mi	28.1	28	20	35	4.7	1.2	16.7	15
	se	29.1	29	23	39	3.8	0.9	13.1	20
	st	26.9	28	20	30	2.8	0.7	10.3	15
Ma length	mi	19.9	20	15	25	2.9	0.8	14.6	15
	se	28.3	28	20	38	4.7	0.8	16.6	34
	st	16.7	17	12	20	2.3	0.6	13.8	15
Ma width	mi	10.8	10	8	17	2.4	0.6	22.5	15
	se	15.2	15	12	20	2.3	0.4	15.2	34
	st	10.6	10	8	14	1.5	0.4	14.2	15
Ma number	mi	2.0	2	2	2	0.0	0.0	0.0	15
	se	2.0	2	2	2	0.0	0.0	0.0	34
	st	4.0	4	4	4	0.0	0.0	0.0	15
Mi diameter	mi	3.4	4	3	4	0.5	0.1	13.3	15
	se	5.8	5	5	8	1.2	0.2	20.4	34
	st	3.0	3	3	3	0.0	0.0	0.0	15
Mi number	mi	2.2	2	2	3	0.4	0.1	18.8	15
	se	2.0	2	2	2	0.0	0.0	0.0	34
	st	3.2	3	3	4	0.4	0.1	11.5	15

Table 1. To be continued.

Character	Species	Mean	Med	Min	Max	SD	SE	CV	n
FC number	mi	3.0	3	3	3	0.0	0.0	0.0	15
	se	3.0	3	3	3	0.0	0.0	0.0	67
	st	3.0	3	3	3	0.0	0.0	0.0	15
BC number	mi	1.0	1	1	1	0.0	0.0	0.0	15
	se	1.0	1	1	1	0.0	0.0	0.0	67
	st	1.0	1	1	1	0.0	0.0	0.0	15
Cirri in ventral row with pTVC number	mi	17.0	17	16	19	1.0	0.3	5.9	15
	se	16.2	16	13	18	1.0	0.1	6.0	67
	st	19.1	19	16	22	1.7	0.4	8.7	15
LMC number	mi	26.9	27	24	31	2.0	1.0	8.0	15
	se	25.3	26	21	28	1.6	0.3	6.5	34
	st	22.5	23	19	25	1.6	0.4	6.9	15
RMC number	mi	26.7	26	23	30	2.0	0.0	7.0	15
	se	33.3	33	30	36	1.5	0.3	13.4	34
	st	26.9	27	23	29	1.5	0.4	5.6	15
TC number	mi	5.0	5	5	5	0.0	0.0	0.0	15
	se	5.0	5	5	5	0.0	0.0	0.0	67
	st	4.0	4	4	4	0.0	0.0	0.0	15
CC number	mi	2.9	3	2	3	0.4	0.1	12.3	15
	se	3.0	3	3	3	0.0	0.0	0.0	34
	st	3.0	3	3	3	0.0	0.0	0.0	15
DK number	mi	6.0	6	6	6	0.0	0.0	0.0	15
	se	6.0	6	6	6	0.0	0.0	0.0	34
	st	6.0	6	6	6	0.0	0.0	0.0	15

at the laboratory, and 20 living and 15 protargol impregnated specimens were observed and biometrically analyzed respectively. Their data were summarized in Table 1.

Description. Body size 90-150 × 28-50 μm *in vivo*, body stiff and somewhat flexible, oval or ellipsoidal in shape, anterior and posterior ends slightly narrow, dorsoventrally flattened about 2 : 1. Cytoplasm colourless, containing some 2-4 μm long yellowish crystals and shiny fat globules. Movement moderately rapid, planktonically gliding and rotating around long axis of body, sometimes crawling on bottom. Cortical granules in narrowly spaced rows, *in vivo* recognizable, spherical contractile vacuole (CV) approximately 20 μm in diameter, located in equatorial region near left margin of cell. Adoral zone of membranelles (AZM) about 1/3 of body length. Pharyngeal fiber 20-35 μm, undulating membranes (uM) in *Oxytricha* pattern. On average three frontal cirri (FC), 30 adoral membranelles (AM), 27 right marginal cirri (RMC), 27 left marginal cirri (LMC), continuous 15 ventral cirral row (VCR) with additional one postoral ventral cirrus (poVC), two pretransverse ventral cirri (pTVC) and five transverse cirri (TC) near posterior end, three inconspicuous caudal cirri (CC), six dorsal kineties (DK) with broken 4th kinety, six dorsal kineties with one CC each associated to kineties 1, 2 and 4. Two oval macronuclei (Ma) with one spherical micronuclei (Mi) respectively, sometimes three micronuclei.

Distribution. Germany, USA, Galapagos Islands, Peru and Korea.

Remarks. The present species is similar to *Gastrostyla dorsicirrata* Foissner, 1982, however, distinguished from it by the following characteristics. The present species is $90\text{--}150 \times 28\text{--}50 \mu\text{m}$ *in vivo* and has cortical granules, six DKs and 14–17 VCRs, while *G. dorsicirrata* is $130\text{--}180 \times 45\text{--}80 \mu\text{m}$ and has no cortical granules, four DKs and 13–15 VCRs (Foissner, 1982; Berger, 1999). The morphological characters of this species in previous local populations are the similar to Korean population but slightly different from those of Korean population. Especially, the numbers of RMC, LMC, cirri in ventral row and AM are different between those of Korean and German population. German population has 33 RMCs, 32 LMCs and 32 AMs, while Korean population has 26 RMCs, 27 LMCs and 30 AMs. In these characters, Korean population are less than those of German population. On the other hand, the body size and the number of cirri in ventral row of Korean population are relatively larger and more than those of German population (Foissner, 1982; Berger, 1999).

2. *Gastrostyla steinii* Engelmann, 1862 (Fig. 2, Table 1)

Gastrostyla steinii Engelmann, 1862, p. 383 (cited from Berger, 1999, p. 791); Kahl, 1935, p. 595; Grim, 1970, p. 486, figs. 1–9; Bick, 1972, p. 184; Walker and Grim, 1973, p. 566, figs. 1–10; Foissner, 1982, p. 71, figs. 16a–e, table. 15; Hemberger, 1982, p. 182, fig. 31a; Foissner, 1991, p. 272; Berger, 1999, p. 791, figs. 199a–p.

Gastrostyla philippinensis Shibuya, 1931, p. 126.

Histrio lemani Dragesco, 1966, p. 89.

Material examined. The living specimens collected from the aeration tank of Onsan sewage treatment plant in Ulsan, Korea ($129^{\circ}21'8''\text{E}$ and $35^{\circ}24'50''\text{N}$), on 25 June 2004, were cultured at the laboratory and 20 living and 15 protargol impregnated specimens were observed and biometrically analyzed respectively. Their data were summarized in Table 1.

Description. Body size $125\text{--}167 \times 50\text{--}72 \mu\text{m}$ *in vivo*, body stiff, ellipsoid in shape, anterior and posterior ends slightly narrow and broadly round, dorsoventrally flattened about 2:1. Cytoplasm colourless, containing some 2–4 μm long yellowish crystals and shiny fat globules. Movement moderately rapid, planktonically gliding and rotating around long axis of body, sometimes crawling on bottom. Cortical granules lacking. Contractile vacuole (CV) with two long collecting canals. Adoral zone of membranelles (AZM) about 40% of body length. Pharyngeal fiber 20–30 μm , undulating membranes (uM) in *Oxytricha* pattern. On average three frontal cirri (FC), 37 adoral membranelles (AM), 27 right marginal cirri (RMC), 23 left marginal cirri (LMC), continuous 17 ventral cirral row (VCR) with additional one postoral ventral cirrus (poVC), two to three pretransverse ventral cirri (pTVC) and four transverse cirri (TC) near posterior end, three caudal cirri (CC), six dorsal kineties (DK), six DKs with one CC each associated to kineties 1, 2 and 4. Four oval macronuclei (Ma) with three to five spherical micronuclei (Mi) near macronuclei.

Distribution. Europe, Japan, Mexico, Philippines, USA and Korea.

Remarks. The present species has long history since 1862 and has been recorded in many countries in Europe, Japan, Mexico, Philippines and USA. *G. steinii* was named as *G. vorax*, *G. philippinensis*, *G. parasteinii* and *Histrio lemani* because of minor differences in the number and the arrangement of the ventral cirral row, and the number of transverse cirri and micronuclei

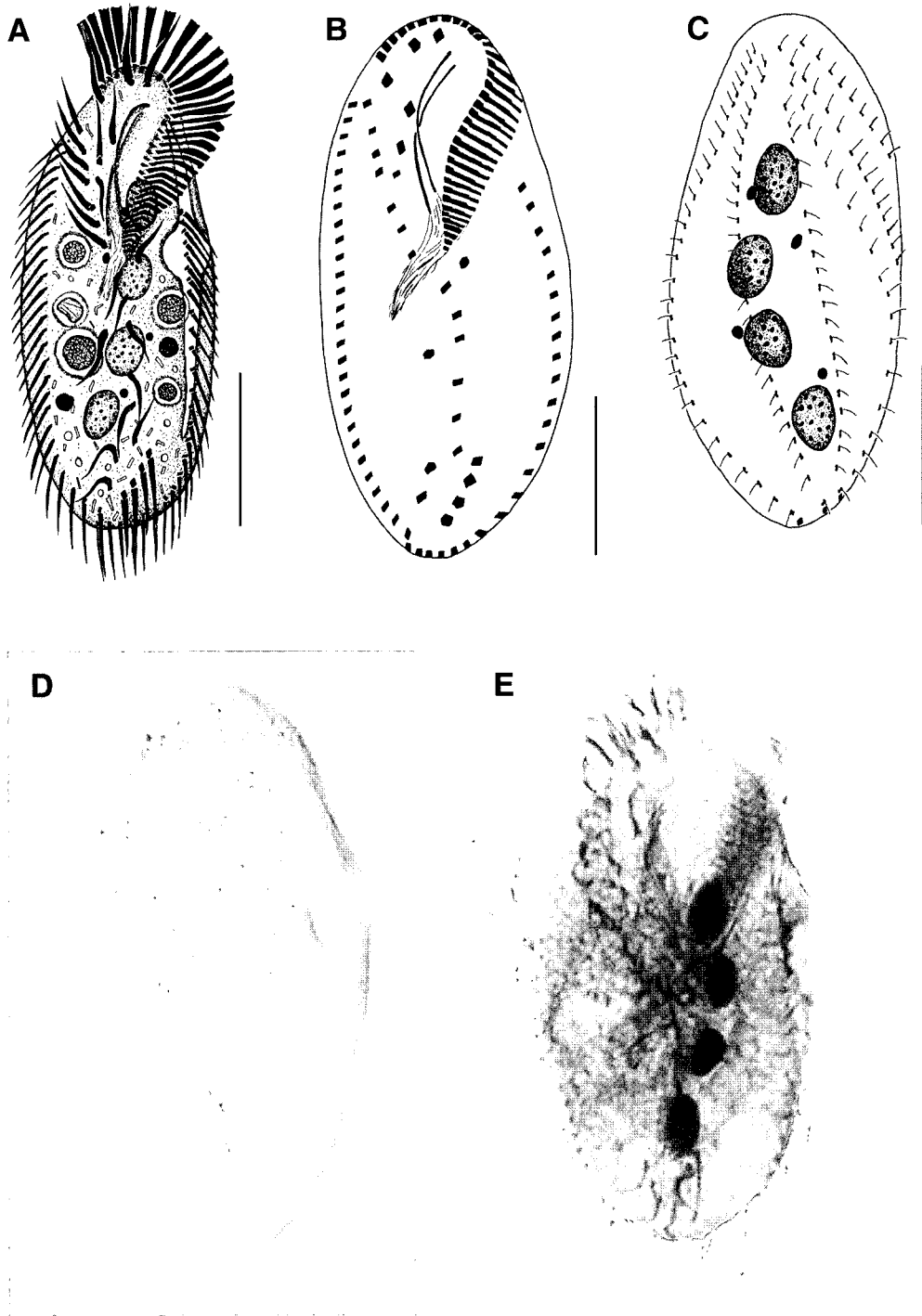


Fig. 2. *Gastrostyla steinii*. A, live specimen, ventral view; B, infraciliature after protargol impregnation ventral view; C, dorsal kineties and nuclear state, dorsal view; D, photograph of contractile vacuole; E photograph of protargol impregnation specimen, ventral view. All scale bars = 50 μ m.

(Berger, 1999). Therefore, these four invalid species are synonymized as *G. steinii* (Shibuya, 1931; Grim, 1970; Foissner et al., 1991; Berger, 1999). This species has been recorded from all around aquatic and territorial environments except in marine or brackish water and sewage treatment plants (Berger, 1999). However, the present species was collected from the sewage treatment plants. The morphological characters of this species in previous local populations are similar to Korean population but slightly different from those of Korean population. Especially, the numbers of LMC, VCR and AM are different between those of Korean and Austrian populations. Austrian population has 28 LMC, while Korean population has 23 LMC on average. In this character, Korean population are less than that of Austrian population, and the body size of Korean population is relatively smaller. On the other hand, Korean population have more the number of VCR and AM than those of Austrian population (Berger, 1999; Foissner, 1982).

3. *Gastrostyla setifera* (Engelmann, 1862) Kent, 1882 (Figs. 3, 4, Table 1)

Gastrostyla setifera Kent, 1882, p. 784; Kahl, 1935, p. 595; Hemberger, 1982, p. 187, fig. 32; Berger, 1999, p. 816, fig. 204a-c; Shi et al., 2003, p. 1411, figs. 1a-f, table. 1.

Pleurotricha setifera Engelmann, 1862, p. 385 (cited from Berger, 1999, p. 816);

Material examined. The living specimens collected from a puddle in the valley of Munsusan Mt. in Ulsan, Korea (129° 14'55"E and 35° 32'31"N), on 19 September 2003, were cultured at the laboratory, and 20 living and 34-67 protargol impregnated specimens were observed and biometrically analyzed respectively. Their data were summarized in Table 1.

Description. Body size 145-198 × 48-80 μm *in vivo*, body stiff, ellipsoid in shape, rounded anteriorly and somewhat narrowed posteriorly. Dorsoventrally flattened about 2 : 1. Cytoplasm colourless, containing some 2-4 μm long yellowish crystals and shiny fat globules. Movement moderately rapid, planktonically gliding and rotating around long axis of body, sometimes crawling on bottom. Cortical granules lacking, spherical contractile vacuole approximately 30 μm in diameter, located in equatorial region near left margin of cell. Adoral zone of membranelles (AZM) about 45% of body length. Pharyngeal fiber 23-39 μm, undulating membranes (uM) in *Oxytricha* pattern. On average three frontal cirri (FC), 51 adoral membranelles (AM), 33 right marginal cirri (RMC), 25 left marginal cirri (LMC), incontinuous 14 ventral cirral row (VCR) with additional two postoral ventral cirrus (poVC), two pretransverse ventral cirri (pTVC) and five transverse cirri (TC) which distinctly separate in two groups near posterior end, three caudal cirri (CC), six dorsal kineties (DK), six DKs with one CC each associated to kineties 1, 2 and 4. Two oval macronuclei (Ma) with one spherical micronucleus (Mi) respectively.

Distribution. China, Germany, Peru and Korea.

Remarks. *G. setifera* is not common species and had not been recorded during 1974-2002 (Berger, 1999; Shi et al., 2003). Recently, this species was rediscovered from China (Shi et al., 2003). This species is very variable in morphological characters. It is not easy to identify this species exactly with small numbers of individuals. For this reason, detailed descriptive statistical data on morphological characters are needed for the correct identification of the species. The differences of characters between those of Korean and Chinese populations are almost nothing. However, the number and the arrangement of ventral cirral row are slightly different between those of Korean and Chinese population. Chinese population have 10 frontal cirri, occasionally 11,

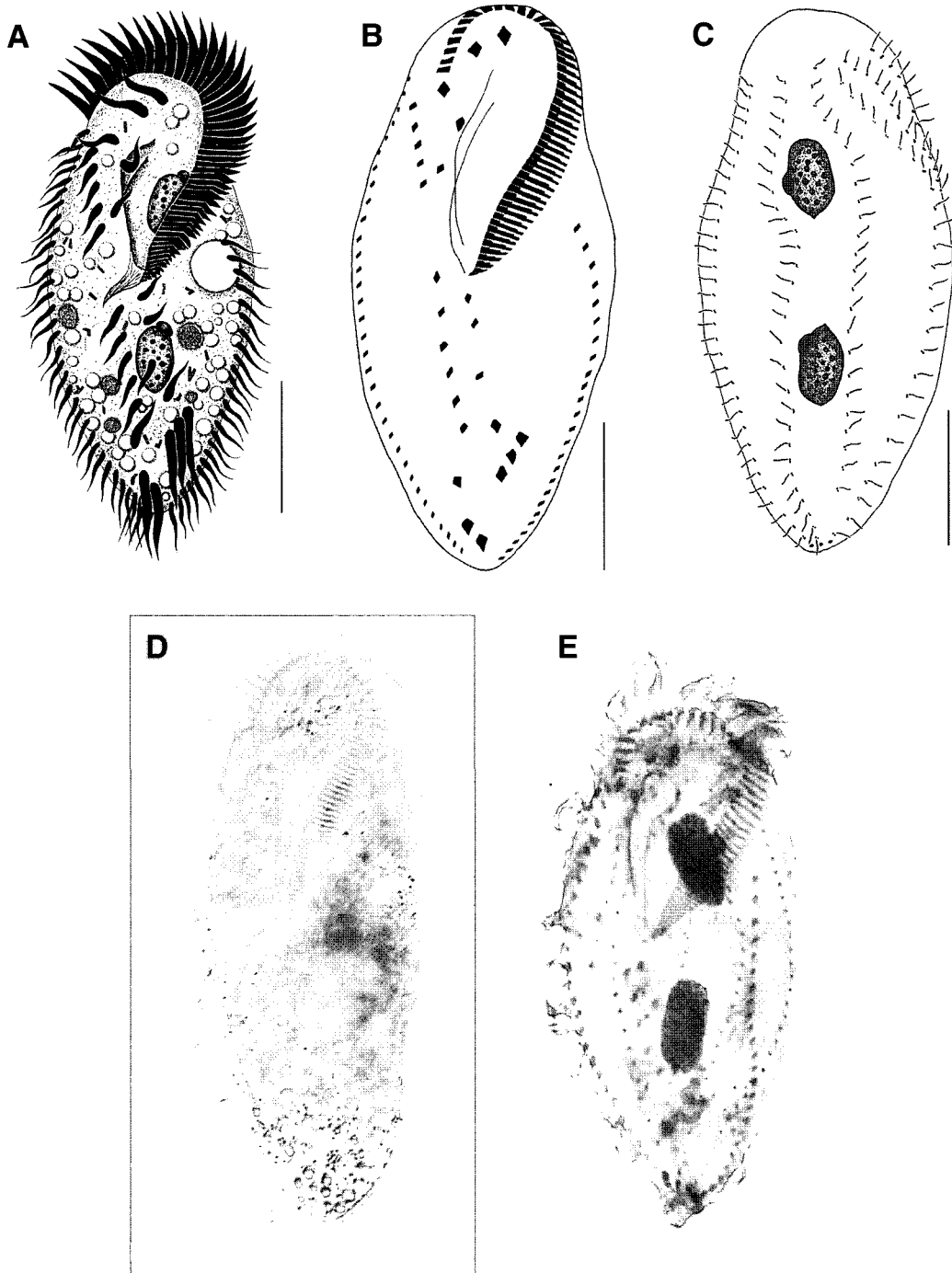


Fig. 3. *Gastrostyla setifera*. A, live specimen, ventral view; B, infraciliature after protargol impregnation, ventral view; C, dorsal kineties and nuclear state, dorsal view; D, photograph of ventral view with contractile vacuole and fat globules; E, photograph of protargol impregnation specimen, ventral view. All scale bars = 50 μm .

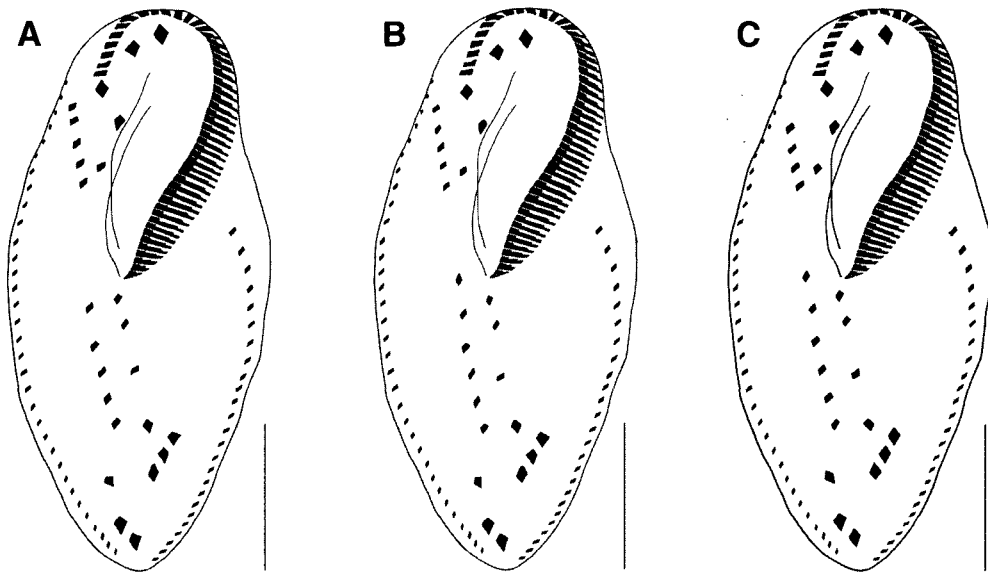


Fig. 4. Variations of ventral cirral row and proportions of its patterns in *Gastrostyla setifera*: A, 6+8 FVC and VCR pattern; 29.4% of 67 protargol impregnated specimens; B, 6+9 FVC and VCR pattern; 23.5% of 67 protargol impregnated specimens; C, 5+9 FVC and VCR pattern; 16.1% of 67 protargol impregnated specimens. All scale bars = 50 μ m.

which include frontal cirri, frontoventral cirri and bucal cirri, besides, nine to 11 ventral cirri which include two pretransverse ventral cirri. However, Korean population has huge morphological variations in these characters. There are three patterns that the arrangement and number of frontoventral cirri and ventral cirri in the present Korean population: according to biometrical characterization data, the proportions of 6+8 FVC and VCR pattern, 6+9 FVC and VCR pattern and 5+9 FVC and VCR pattern shows 29.4%, 23.5% and 16.1% respectively (Fig. 4a-c). Thus, the present species can be confused with other species because of biometrical variations in these morphological characters. This species is distinguished from the other *Gastrostyla* species by the unique arrangement of transverse cirri which are separated in two groups of two and three cirri, while others have unseparated one group of about five cirri.

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한국미기록 *Gastrostyla* 섬모충 (Ciliophora: Spirotrichea:
Stichotrichida) 3종의 형태적 변이와 재기재

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요 약

하수처리장과 계곡의 웅덩이에서 채집된 3종의 *Gastrostyla* 섬모충류가 *Gastrostyla minima* Hemberger, 1985, *G. steinii* Engelmann, 1862 그리고 *G. setifera* (Engelmann, 1862)로 동정되었다. 기재는 생체표본, protargol 염색표본 관찰과 관찰된 표본의 형태통계에 기초하여 기술하였다. 이 종들의 형태적 변이는 측정된 형질의 기술통계치리로 분석되었다. 이들 3종은 한국에서 처음으로 기록되는 종으로 아래의 식별형질로 구분된다. *G. minima*는 일반적으로 2개의 대핵에 구형의 소핵이 하나씩 있고, 하나의 후방구복극모 (poVC, postoral ventral cirri)와 연속적인 복극모섬모열 (VCR, ventral cirral row), 5개의 후방극모 (TC), 6개의 등쪽섬모열에서 네 번째 섬모열은 끊어져 있고 cortical granules들을 가진다. *G. steinii*는 4개의 대핵과 3-5개의 소핵을 가지고, 하나의 후방구복극모 (poVC)와 연속되지 않는 복극모섬모열, 4개의 후방극모, 6개의 등쪽섬모열을 가지며 cortical granules들이 없다. *G. setifera*는 2개의 대핵에 구형의 소핵이 하나씩 있고, 두 그룹으로 뚜렷하게 나누어진 5개의 후방극모가 있으며, 6개의 등쪽섬모열, 두개의 후방구복극모와 연속되지 않는 복극모섬모열을 가지며 cortical granules은 없다.