Primary structure, expression and localization of two intermediate subunit lectins of *Entamoeba dispar* that contain multiple CXXC motifs

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SUMMARY

We have recently identified 2 surface proteins in *Entamoeba histolytica* as intermediate subunits of galactose- and *N*-acetyl-D-galactosamine-inhibitable lectin (EhIgl1 and EhIgl2); these proteins both contain multiple CXXC motifs. Here, we report the molecular characterization of the corresponding proteins in *Entamoeba dispar*, which is neither pathogenic nor invasive. Two *Igl* genes encoding 1110 and 1106 amino acids (EdIgl1 and EdIgl2) were cloned from 2 strains of *E. dispar*. The amino acid sequence identities were 79% between EdIgl1 and EdIgl2, 75–76% between EdIgl1 and EhIgl1, and 73–74% between EdIgl2 and EhIgl2. However, all the CXXC motifs were conserved in the EdIgl proteins, suggesting that the fold conferred by this motif is important for function. Comparison of the expression level of the *Igl* genes by real-time RT-PCR showed 3–5 times higher expression of *EdIgl1* compared to *EdIgl2*. Most EdIgl1 and EdIgl2 proteins were co-localized on the surface and in the cytoplasm of trophozoites, based on confocal microscopy. However, a different localization of EdIgl1 and EdIgl2 in intracellular vacuoles and a different level of phenotypic expression of the two Igls were also observed. These results demonstrate that Igls are important proteins even in non-pathogenic amoeba and that Igl1 and Igl2 may possess different functions.

Key words: *Entamoeba dispar*, *Entamoeba histolytica*, intermediate subunit of Gal/GalNAc lectin (Igl), cysteine-rich protein.

INTRODUCTION

It has been estimated that 480 million people worldwide are infected with *Entamoeba histolytica* or *Entamoeba dispar* (Walsh, 1986). *E. histolytica* is the causative agent of human amoebic colitis and liver abscess, which result in up to 110 000 deaths annually. *E. dispar* is morphologically indistinguishable from *E. histolytica*, but is non-pathogenic and non-virulent (Diamond and Clark, 1993). Adherence of *E. histolytica* trophozoites to host cells is an essential step in its pathogenicity, and it is well known that the 170 kDa heavy subunit of galactose- and *N*-acetyl-D-galactosamine (Gal/GalNAc)-inhibitable lectin (Hgl) is the key factor in adherence and subsequent pathogenesis of the amoeba (Petri *et al.* 2002). Hgl is a transmembrane protein that forms a heterodimer with a glycosylphosphatidylinositol (GPI)-anchored 35 kDa light subunit (Lgl) via disulfide bonds (Petri *et al.* 1989). Recently, we have identified a GPI-anchored 150 kDa intermediate subunit (Igl) of lectin, which is non-covalently associated with Hgl (Cheng *et al.* 1998, 2001). There are 2 isoforms of Igl, which consist of 1101 and 1105 amino acids and are referred to as Igl1 and Igl2, respectively; both are cysteine-rich proteins containing multiple CXXC motifs. A mouse monoclonal antibody (mAb) to Igl significantly inhibits adherence and cytotoxicity of trophozoites to mammalian cells *in vitro* and also inhibits liver abscess formation in hamsters (Tachibana *et al.* 1997; Cheng *et al.* 1997, 1999). Antibodies to Igl have been detected not only in symptomatic patients with amoebiasis but also in asymptomatic cyst passers of *E. histolytica* (Tachibana *et al.* 2004). Immunization of hamsters with affinity-purified Igl can prevent amoebic liver abscess formation (Cheng and Tachibana, 2001), and Igl has also been detected in the *E. histolytica* fraction that interacts with the brush border of enterocytes (Seigneur *et al.* 2005). Therefore, Igl seems to be one of the key molecules in amoebic adherence to host cells and pathogenicity; however, the correlation of these effects with

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each Igl isoform and the differences between the isoforms are not known.

Comparison of *E. histolytica* and *E. dispar* is also of importance for understanding the pathogenicity of amoeba. One well-known difference between the two species is associated with the family of cysteine proteases that are pathogenic factors in *E. histolytica*; in *E. dispar*, the *EhCP1* gene is absent and *EhCP5* is degenerate (Bruchhaus *et al*. 1996; Willhoeft *et al*. 1999). Concerning lectins, it has been reported that Hgl is present in *E. dispar*, but that its expression level is lower than that in *E. histolytica* (Pillai *et al*. 1997, 2001). Therefore, it is of interest to determine if Igl1 and Igl2 are expressed in *E. dispar*. We report here the primary structure of the 2 Igl isoforms in 2 *E. dispar* strains isolated from human and cynomolgus monkey, respectively. We also compared the expression levels of *Igl* genes between *E. dispar* and *E. histolytica*, and examined the expression and localization of Igl1 and Igl2 in *E. dispar*.

MATERIALS AND METHODS

Cultivation of parasites

Trophozoites of the *E. dispar* SAW1734RclAR strain were grown axenically or monoxenically with sterilized *Crithidia fasciculata* in YIGADHA-S medium supplemented with 15% adult bovine serum at 37 °C (Kobayashi *et al*. 2005; Khalifa *et al*. 2006). Trophozoites of the *E. dispar* CYNO9:TPC strain were axenically cultured in the YIGADHA-S medium. Trophozoites of *E. histolytica* HM-1:IMSS were axenically cultured in TYI-S-33 medium supplemented with 15% adult bovine serum at 37 °C (Diamond *et al*. 1978). Cultured trophozoites were harvested in the logarithmic phase of growth and used in subsequent experiments.

Construction of a cDNA library and cloning of the Igl *gene*

Poly(A) RNA of *E. dispar* SAW1734RclAR trophozoites was isolated using a QuickPrep mRNA purification kit (Amersham Pharmacia). A cDNA library was constructed from 5 μg of poly(A) RNA using a cDNA synthesis kit (Amersham Pharmacia) and a λgt11 vector kit (Stratagene). The library was screened with a 657 bp probe using the Gene Images AlkPhos Direct labelling and detection system (Amersham Pharmacia). The probe was prepared from plasmid DNA containing the *E. histolytica Igl1* gene by PCR amplification using primers EhIgl1-S877 (5′-CCC TCG AGT CAA ATG GTG AAT GTA AGC C-3′) and EhIgl1-AS1088 (5′-CCC TCG AGT TAA ATG CCT TTA GCT CCA TT-3′) (Tachibana *et al*. 2004). The positive clone containing the longest insert was subcloned into a pUC19 vector and sequenced. To extend the sequence of the 5′ end, rapid amplification of the cDNA end was performed with a 5′-Full RACE Core Set (Takara). For the cloning of the other *Igl* gene, the cDNA library was subjected to PCR using primers 5′-CAA TTT CAC TTG GTG AGT ACA AAG CTG-3′ (forward) and 5′-GAA AAT TCC TTT ACT TCC ATT GCA GTT TCC-3′ (reverse). These primers were prepared based on the sequence of the first cloned *E. dispar Igl* gene, with reference to the location of common sequences between the two *E. histolytica Igl* genes. The amplified genes were cloned using a TOPO TA Cloning Kit (Invitrogen) and sequenced. To extend the sequence of the 5′ and 3′ ends of the cloned DNA, a 5′-Full RACE Core Set and 3′-Full RACE Core Set were used (Takara). For the cloning of *Igl* genes from the CYNO9:TPC strain, genomic DNA isolated as previously described (Tachibana *et al*. 1991) was used as a template for PCR, using the forward primers 5′-ATG TTT ATT ATT CTT TTA TTC ATA TCA ATT TCA C-3′ (*Igl1*) and 5′-ATG TTT ATT CTT CTT TTA TTT ATA TCA ATT TCA C-3′ (*Igl2*), and the reverse primer 5′-TTA GAA CAT AAA TGA TAA CAT GAC TAT CAC CAT C-3′. Thirty-five cycles of PCR using *Pyrobest* DNA polymerase (Takara) were performed as follows: denaturation at 94 °C for 15 s (195 s in cycle 1), annealing at 58 °C for 30 s, and polymerization at 72 °C for 180 s (600 s in cycle 35). Amplified DNA was cloned using a Zero Blunt TOPO PCR Cloning Kit (Invitrogen) and sequenced. Nucleotide sequence data were analysed using Genetyx-Mac ver. 11.

Southern blot analysis

Genomic DNA was isolated from *E. dispar* SAW-1734RclAR trophozoites as described previously (Tachibana *et al*. 1991). Three μg of genomic DNA was digested with restriction enzymes *Dra*I, *Taq*I and *Hin*dIII. The fragments were separated on a 1% agarose gel, transferred to a Hybond N^+ membrane (Amersham Pharmacia) by capillary action, and fixed by alkaline denaturation. The membrane was hybridized at 55 °C in buffer containing a Gene Images AlkPhos Direct-labelled probe (Amersham Pharmacia) prepared by PCR amplification of cloned cDNA. The primers used for amplification were 5′-AGA TGG ATT CTA TTT TGA TGA-3′ (forward) and 5′-CAT ATG TCT TGA ACA TGG-3′ (reverse). The blots were detected using a CDP-star detection reagent (Amersham Pharmacia) and exposed to autoradiography films.

Real-time RT-PCR analysis

Total RNAs of *E. dispar* and *E. histolytica* trophozoites isolated using an RNeasy mini kit (Qiagen) were used for cDNA synthesis with a GeneAmp RNA PCR kit (Applied Biosystems). Reaction mixtures for quantitative real-time PCR analysis were

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prepared using SYBR Premix Ex *Taq* (Takara), specific primers, Rox dye, and the cDNAs. The primers used were as follows: 5′-TGA CAA AGA CAA TAC TTG TAA AAA GTG-3′ (forward) and 5′-ATT ACT AAC ACA TGC ACA TTT TTT GTC-3′ (reverse) for *E. dispar Igl1* genes; 5′-TCG ATG AAA ATA ATG TAT GCC AGA AAT-3′ (forward) and 5′-TCA TCA AGG CAA GCA CAT TGA CTG-3′ (reverse) for *E. dispar Igl2* genes; 5′-GTT CAC AGG TTG GTG CTT GTA CG-3′ (forward) and 5′-ACA GTA CAT GGC TTT TCT CCG GTA-3′ (reverse) for *E. histolytica Igl1* genes; 5′-GAT TCA CAA ACA AAG GAG TGT GCC-3′ (forward) and 5′-GTG CAT TTG AAC CAC TAG CAG CAA-3′ (reverse) for *E. histolytica Igl2* genes; and 5′-CCA GCT ATG TAT GTT GGA ATT CAA G-3′ (forward) and 5′-GAT CAA GTC TAA GAA TAG CAT GTG G-3′ (reverse) for *actin* genes. Forty cycles of amplification with recording of fluorescence intensity in each cycle were performed using an ABI PRISM 7700 Sequence Detection System (Applied Biosystems). After initial denaturation at 95 °C for 10 sec, a shuttle PCR protocol consisting of denaturation at 95 °C for 5 sec and annealing-extension at 60 °C for 30 sec was applied. Relative quantitation with data from the ABI PRISM 7700 Sequence Detection System software version 1.7 was performed by the comparative C_T method, using the actin gene as an internal standard. The experiments were repeated 3 times, including the steps of culture of trophozoites and isolation of RNA.

Expression of recombinant Igl1 *and* Igl2

DNA fragments encoding full-length Igls, except for the N-terminus and C-terminus signal sequences, were obtained by PCR amplification of cloned *Igl* genes. Primers EdIgl1-S14-Xho (5′-CCC TCG AGG AGT ACA AAG CTG ATA AAC T-3′) and EdIgl-AS-Xho (5′-CCC TCG AGT TAA ATT CCT TTA CTT CCA TT-3′) were used for amplification of the *Igl1* gene of SAW1734RclAR. For amplification of the *Igl2* gene of SAW1734RclAR, primers EdIgl2-S14-Xho (5′-CCC TCG AGG ATT ACA AAG CTG ATA AAC TCA TC-3′) and EdIgl-AS-Xho were used. PCR was performed as previously described (Tachibana *et al*. 2004). Each amplified DNA fragment was digested with *Xho*I, purified, and ligated with pET19b vector (Novagen). The plasmid was introduced into competent *Escherichia coli* JM109 cells and the direction and sequence of inserts were confirmed. *E. coli* BL21Star(DE3)pLysS cells (Invitrogen) were transformed with the cloned plasmids. Each clone was cultured in 400 ml of Luria-Bertani medium containing ampicillin until the culture reached an optical density of 0·6 at 600 nm. Isopropyl-β-D-thiogalactopyranoside was added to the cultures at a final concentration of 1 mM, and the cultures were incubated at 37 °C for 3 h. Preparation of inclusion bodies and refolding of the proteins were performed as previously described (Tachibana *et al*. 2004).

Production of specific mAbs

MAbs to Igl1 and Igl2 of *E. dispar* SAW1734RclAR were prepared as follows. Six-week-old male BALB/c mice were inoculated intraperitoneally with 10 μg of recombinant proteins in Freund's complete adjuvant and were inoculated again after 2 weeks. After an additional 3 weeks, the mice received only recombinant proteins. Four days later, spleen cells of immunized mice were isolated and fused with X63 Ag8.653 mouse myeloma cells using 50% polyethylene glycol 1500. Hybridomas secreting mAbs against *E. dispar* Igls were screened by immunofluorescent staining and ELISA, and were cloned by limiting dilution. Immunoglobulin isotypes of mAbs were determined by immunofluorescent staining using subtype-specific antibodies. Ascites was obtained by intraperitoneal inoculation of hybridomas into pristine-primed mice, and immunoglobulin was purified using an Affi-Gel protein A MAPS II kit (Bio-Lab).

Dot blot analysis

Recombinant Igls and sonicated trophozoites of *E. dispar* SAW1734RclAR were blotted on the nitrocellulose membrane using a Bio-Dot microfiltration apparatus (Bio-Rad). Filter strips were blocked with 3% bovine serum albumin (BSA) in phosphate-buffered saline (PBS) and reacted with mouse anti-*E. dispar* Igl mAbs for 30 min. After being washed with PBS containing 0·05% Tween-20 (PBS-Tween), the strips were incubated with horseradish peroxidase (HRP)-labelled goat anti-mouse IgG antibody (MP Biomedicals) for 30 min. The strips were then washed with PBS-Tween and developed with a Konica Immunostaining HRP-1000 kit.

SDS-PAGE and Western blot analysis

Recombinant Igl proteins or *E. dispar* trophozoites were treated with Laemmli's sample buffer (Laemmli, 1970) containing 2 mM phenylmethylsulfonyl fluoride, 2 mM *N*-α-*p*-tosyl-L-lysine chloromethylketone, 2 mM *p*-hydroxymercuriphenylsulfonic acid, and 4 μM leupeptin for 5 min at 95 °C and then subjected to sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE). Western blot analysis was performed as previously described (Tachibana *et al*. 2004).

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Flow cytometry

Immunophenotypic surface staining of Igl1 and Igl2 using flow cytometry was performed on trophozoites of *E. dispar* SAW1734RclAR strain. Intact cells were incubated on ice with 3% BSA in PBS for 15 min, and then with a mixture of mAbs ED1-13 and ED2-1 for 15 min. After washing with ice-cold PBS, the cells were incubated with a mixture of Alexa Fluor 488-labelled goat anti-mouse IgG2b-specific antibody (Molecular Probes) and PE-labelled goat anti-mouse IgG1-specific antibody (Santa Cruz Biotechnology) for 15 min on ice. The cells were washed with ice-cold PBS and then fixed in 4% paraformaldehyde. Aliquots of approximately 5000 cells per sample were analysed using FACS Calibur (Becton Dickinson), with data analysis using CellQuest Software (BD Immunocytometry systems).

Confocal microscopy

E. dispar SAW1734RclAR trophozoites were fixed with 4% paraformaldehyde in PBS and attached to silane-coated glass slides using Shandon Cytospin 2. After washing with PBS, the glass slides were incubated with 10% sucrose in PBS for 1 h and then stored at −80 °C until use. For double staining of Igl1 and Igl2, fixed trophozoites on the slides were treated with 0·1% Triton X-100 in PBS for 5 min, blocked with 3% BSA in PBS for 30 min and then incubated for 1 h at room temperature with a mixture of 2 mAbs, ED1-13 and ED2-1. After washing, the slides were incubated with a mixture of Alexa Fluor 488-labelled goat anti-mouse IgG2b-specific antibody and Alexa Fluor 594-labelled goat anti-mouse IgG1-specific antibody (Molecular Probes) for 1 h. The stained trophozoites were mounted using glycerol containing 1·25 mg/ml 1,4-diazbicyclo(2,2,2)octane and 10% PBS, and the samples were observed using a Zeiss LSM510 META confocal laser scanning microscope.

RESULTS

Cloning of genes encoding E. dispar *Igl1 and Igl2*

Two *Igl* genes cloned from the cDNA library from the *E. dispar* SAW1734RclAR strain encoded proteins of 1110 and 1106 amino acids, respectively, with calculated molecular masses of 120·9 kDa and 120·3 kDa and theoretical p*I* values of 5·5 and 4·87, respectively (DDBJ, EMBL, and GenBank Accession numbers AB287423 and AB287424). Two *Igl* genes were also cloned from the genomic DNA of the *E. dispar* CYNO9:TPC strain. These genes also encoded proteins of 1110 and 1106 amino acids, respectively, with calculated molecular masses of 121·0 kDa and 120·4 kDa and theoretical p*I* values of 5·41 and 4·74, respectively (DDBJ, EMBL, and GenBank Accession numbers AB287425 and AB287426). Based on the similarity of the p*I* values to those of Igls of *E. histolytica* (5·52 for Igl1 and 5·17 for Igl2) (Cheng *et al*. 2001), the former protein was designated as Igl1 and the latter as Igl2 in both *E. dispar* strains. Multiple alignments of amino acid sequences among these Igl proteins and other *E. histolytica* Igls are shown in Fig. 1; the amino acid identity between *E. dispar* Igl1 and Igl2 was 79% in both strains. Differences in amino acids between the proteins in the two *E. dispar* strains were greater for Igl2 than for Igl1. In comparison with the *E. histolytica* Igl isoforms, the amino acid sequence identities were 75–76% for Igl1 and 73–74% for Igl2. Insertions of 6 amino acids in Igl1 and Igl2 are present in the two *E. dispar* strains around position 840. However, all cysteine residues found in *E. histolytica* Igl proteins were conserved in the *E. dispar* proteins. Both *E. dispar* Igl isoforms also contained hydrophobic amino- and carboxy-terminal signal sequences consistent with a GPI-anchored plasma membrane protein, and all Igl sequences contained a signature epidermal growth factor-like domain close to the C-terminus. The nucleotide sequence identities were 88% between the *E. dispar Igl1* and *Igl2* genes, 83% between the *E. dispar and E. histolytica Igl1* genes, and 82% between the *E. dispar* and *E. histolytica Igl2* genes.

A BLAST search of *E. dispar* SAW760 strain genomic sequences <http://www.ncbi.nlm.nih.gov/BLAST/>was performed, although the *E. dispar* genome project is incomplete. An identical sequence to that of the *Igl1* gene of the SAW1734-RclAR strain was found (Genbank Accession no. AANV01000026), and 2 sequences (AANV01000644 and AANV01001389) were identified that showed 99% identity with the *Igl2* gene of SAW1734RclAR in partially overlapping regions.

Southern blot analyses of Igl *genes*

Southern blot hybridization using a 420-bp PCR product as a probe was performed on *E. dispar* SAW1734RclAR genomic DNA digested with *Dra*I, *Taq*I and *Hin*dIII (Fig. 2). The results indicated the presence of 2 *Igl* genes in the *E. dispar* genomic DNA.

Real-time RT-PCR analysis of Igl *genes*

Expression levels of *Igl1* and *Igl2* are compared in Fig. 3. In the SAW1734RclAR strain, expression of *Igl1* was 3 times higher than that of *Igl2* ($P<0·001$), and in the CYNO9:TPC strain, expression of *Igl1* was 5 times higher than that of *Igl2* ($P<0·01$). Higher expression of *Igl1* compared to *Igl2* was also observed in *E. histolytica* ($P<0·001$). Expression of *Igl1* was lower in *E. dispar* than in *E. histolytica* (SAW1734RclAR *vs* HM-1:IMSS, $P<0·01$;

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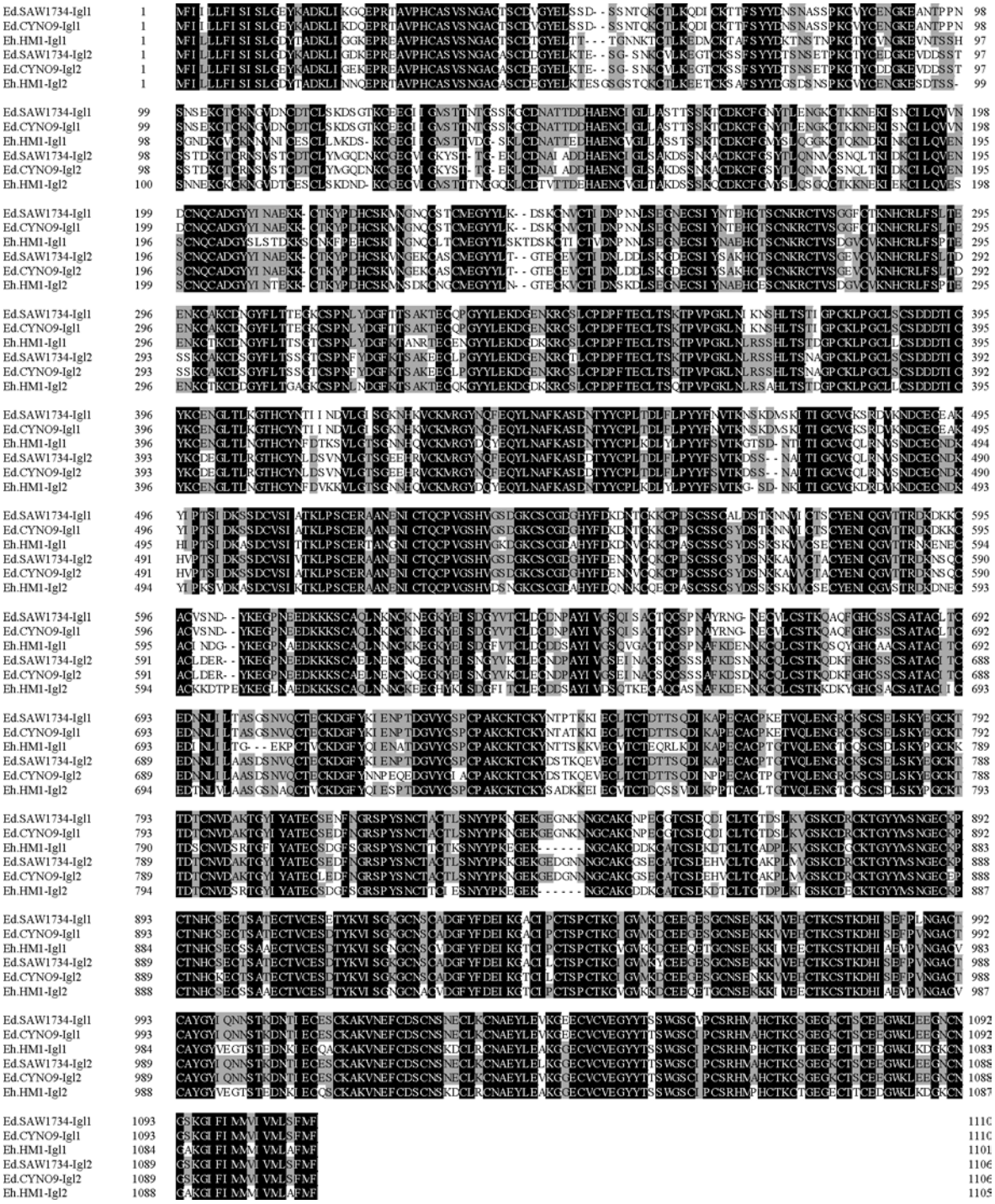

Fig. 1. Alignment of the deduced amino-acid sequences of the *Igl1* and *Igl2* genes from *Entamoeba dispar* SAW1734RclAR (Ed.SAW1734), *E. dispar* CYNO9:TPC (Ed.CYNO9) and *E. histolytica* HM-1:IMSS (Eh.HM1). Identical and conserved amino-acid residues are highlighted in black and grey, respectively.

CYNO9:TPC *vs* HM-1:IMSS, not significant), whereas *Igl2* expression was similar in the two species.

Dot blot and Western blot analyses of Igls

Full length (except for the signal sequence) recombinant *E. dispar* Igls from the SAW1724RclAR strain were prepared in *Escherichia coli*. The apparent molecular weight of the recombinant protein with the leader peptide was slightly larger for Igl2 (190 kDa) than for Igl1 (170 kDa) in SDS-PAGE under reducing conditions (data not shown). Recombinant Igl1 and Igl2 proteins were used for immunization of mice to prepare mAbs specific for each Igl. In dot blot analysis, mAb ED1-13 reacted specifically with recombinant Igl1, but not with recombinant Igl2; in contrast, mAb ED2-1 was

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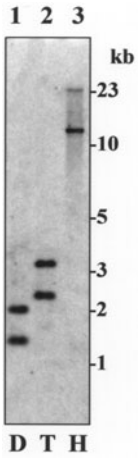


Fig. 2. Southern blot analysis of *Igl* genes in *Entamoeba dispar* SAW1734RclAR. Genomic DNA was digested with *Dra*I (D, lane 1), *Taq*I (T, lane 2) and *Hin*dIII (H, lane 3) and hybridized with the probe. The blot is representative of 2 independent experiments. Numbers to the right indicate the sizes of DNA markers (in kilobases).

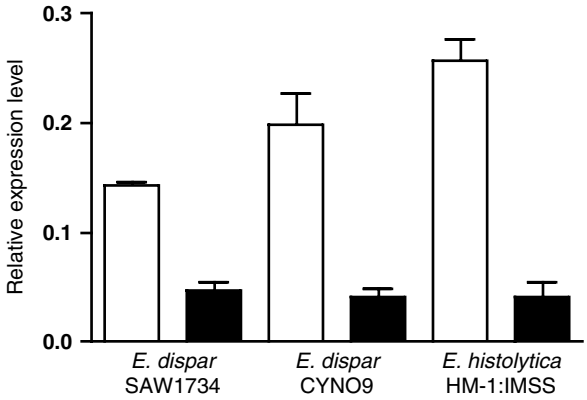
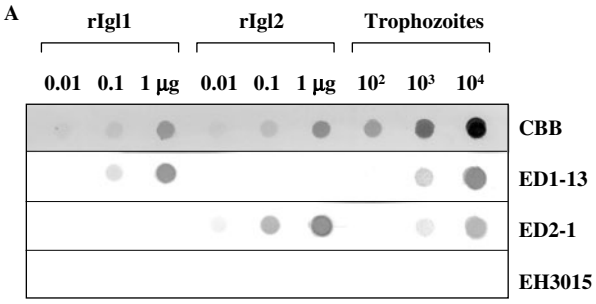


Fig. 3. Real-time reverse transcription PCR analysis of *Igl* genes from *Entamoeba dispar* and *E. histolytica*. Expression levels of *Igl1* (open bars) and *Igl2* (filled bars) in trophozoites from *E. dispar* SAW1734RclAR, *E. dispar* CYNO9:TPC and *E. histolytica* HM-1:IMSS are expressed as values relative to the expression level of *actin*. Vertical bars indicate the S.E. of the mean from 3 experiments.



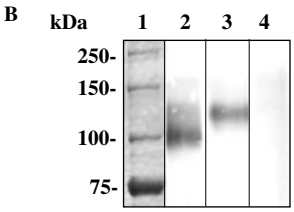


Fig. 4. (A) Reactivity of anti-Igl monoclonal antibodies to recombinant Igls and crude antigens of *Entamoeba dispar* in dot blot analysis. Various concentrations (0·01, 0·1 and 1 μg) of recombinant Igl1 (rIgl1) and recombinant Igl2 (rIgl2) and various numbers (10^2, 10^3 and 10^4) of sonicated trophozoites from strain SAW1734RclAR were spotted on nitrocellulose membranes. One strip was stained with Coomassie brilliant blue (CBB). Other strips were treated with anti-*E. dispar* Igl monoclonal antibodies (ED1-13, ED2-1) and anti-*E. histolytica* Igl monoclonal antibody (EH3015). HRP-conjugated goat antibody to mouse IgG was used as a secondary antibody. The blot is representative of 2 independent experiments. (B) Western immunoblot analysis of native Igls of *E. dispar*. Lysates of SAW1734RclAR trophozoites were subjected to SDS-PAGE in a 7·5% gel under non-reducing conditions and transferred to polyvinylidene difluoride membranes. Protein bands of the size marker in lane 1 were stained with Coomassie brilliant blue. The strips were treated with monoclonal antibodies as follows: lane 2, ED1-13; lane 3, ED2-1; and lane 4, EH3015. HRP-conjugated goat antibody to mouse IgG was used as a secondary antibody. The blot is representative of 3 independent experiments. The numbers to the left indicate molecular masses (in kilodaltons).

reactive specifically with recombinant Igl2 (Fig. 4A). In conditions under which the reactivity of these mAbs to *E. dispar* trophozoites was comparable, differences in reactivity to equal amounts of recombinant Igls were observed. The reactivity of mAb ED1-13 to 10^4 trophozoites was similar to the reactivity to 1 μg of EdIgl1, whereas the reactivity of mAb ED2-1 to 10^4 trophozoites were comparable to the reactivity to 0·1 μg of EdIgl2, suggesting that the amount of Igl2 was approximately one-tenth that of Igl1 in the trophozoites. In Western blot analysis using trophozoites from the SAW1734RclAR strain, mAbs ED1-13 and ED2-1 recognized a 100 kDa and a 120 kDa band, respectively, under non-reducing conditions (Fig. 4B). No bands were detected in the Western blot under reducing conditions, indicating that the mAbs recognized discontinuous epitopes on the Igl proteins.

Phenotypic expression of Igls on the surface of trophozoites

To compare the amounts of Igl1 and Igl2 expressed on the surface of trophozoites from the *E. dispar* SAW1724RclAR strain, flow cytometric analysis was performed using specific mAbs for each Igls (Fig. 5). The results demonstrated that almost all

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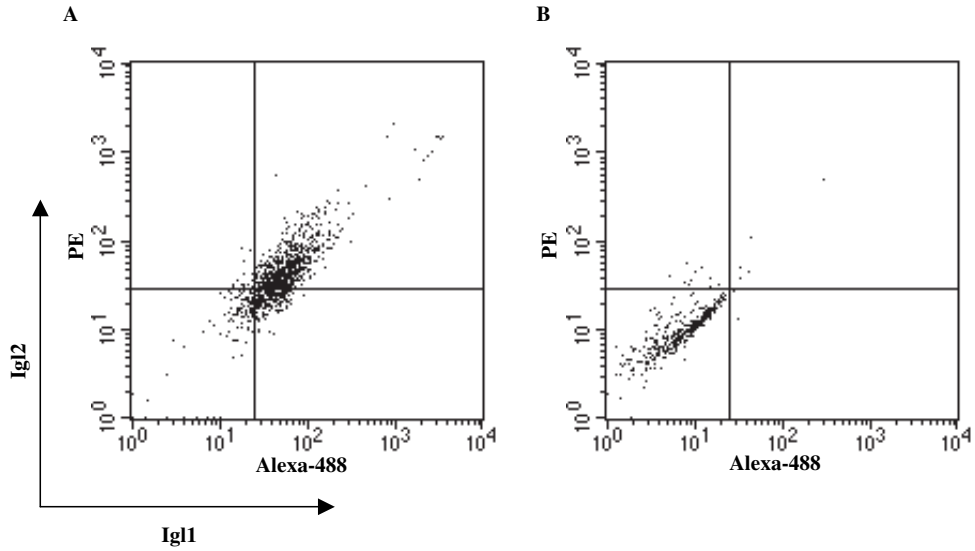

Fig. 5. Flow cytometric analysis of phenotypic expression of Igl1 and Igl2 on the surface of *Entamoeba dispar* trophozoites. Intact trophozoites from the SAW1734RclAR strain were double stained with monoclonal antibodies ED1-13 (specific for Igl1, IgG2b) and ED2-1 (specific for Igl2, IgG1), followed by Alexa Fluor 488-labelled goat anti-mouse IgG2b-specific antibody and PE-labelled goat anti-mouse IgG1-specific antibody (A). The control was stained only with secondary antibodies (B). The results are representative of 3 independent experiments.

trophozoites expressed both Igl1 and Igl2 on the cell surface.

Localization of Igls on trophozoites

Localization of Igl1 and Igl2 on *E. dispar* trophozoites was examined by confocal laser scanning microscopy using specific mAbs. Both Igls were localized on the plasma membrane and in cytoplasm in all trophozoites (Figs 6 and 7). However, the amount of each Igl in the trophozoites was variable, especially in the cytoplasm; that is, Igl1- and Igl2-dominant cells were present (arrows and arrowheads in Fig. 6). In addition, Igl1- and Igl2-dominant vacuoles were also observed within a single trophozoite (arrow and arrowhead in Fig. 7).

DISCUSSION

Comparison of the 2 *Igl* genes cloned from *E. dispar* with those from *E. histolytica* indicated differences in the sequences of the corresponding proteins in *E. dispar* and *E. histolytica* and in the 2 strains of *E. dispar*. However, all the cysteine residues, including the CXXC motifs, were conserved between species and between strains, which suggests that the fold of the protein is maintained and is important for its function. Amino acid identities of Igl1 and Igl2 within species (79% in *E. dispar* and 81% in *E. histolytica*; Cheng *et al*. 2001) were higher than those for each Igl between the 2 species (75–76% for Igl1 and 73–74% for Igl2). Insertions of 6 amino acids around position 840 in *E. dispar* were present in both Igl1 and Igl2, as shown in Fig. 1. Nucleotide identities of the 2 *Igl* genes were also higher within species, compared to the respective identities of the *Igl* genes between *E. dispar* and *E. histolytica*. These results suggest that duplication of the genes may have occurred after divergence of the species.

The properties of the Gal/GalNAc lectin of *E. histolytica* were demonstrated in a 150 kDa fraction purified by affinity chromatography using the *E. histolytica*-specific mAb EH3015 (Cheng *et al*. 1998). In addition, Igl1 and Igl2 of *E. histolytica* have been detected, in addition to Hgl and Lgl, in the protein fraction that binds specifically to GalNAc-BSA-coated magnetic beads (McCoy and Mann, 2005). However, when we performed a preliminary examination of the reactivity of recombinant Igls from *E. histolytica* and *E. dispar* with $GalNAc_{27}$-BSA by dot blot analysis and surface plasmon resonance, we could not prove that the recombinant proteins had sugar-binding properties (data not shown). Therefore, the Igls may exist as part of the lectin complex, perhaps with non-covalent association to another protein containing a sugar-binding site, with this association occurring either directly or being mediated by a third protein. Recently, it has been reported that Igl of *E. histolytica* is found in the protein fraction that interacts with purified brush border from human enterocytes (Seigneur *et al*. 2005). It has also been demonstrated that the 140 kDa fibronectin-binding molecule of *E. histolytica* (Talamas-Rohana *et al*. 1992) is identical with Igl2 (Hernandez-Ramirez *et al*. 2007). These observations indicate that Igls are important proteins for amoebic adherence to host cells, and since Igls are also expressed in the non-pathogenic amoeba, it seems likely that these proteins are important for colonization of amoebae in the large intestine.

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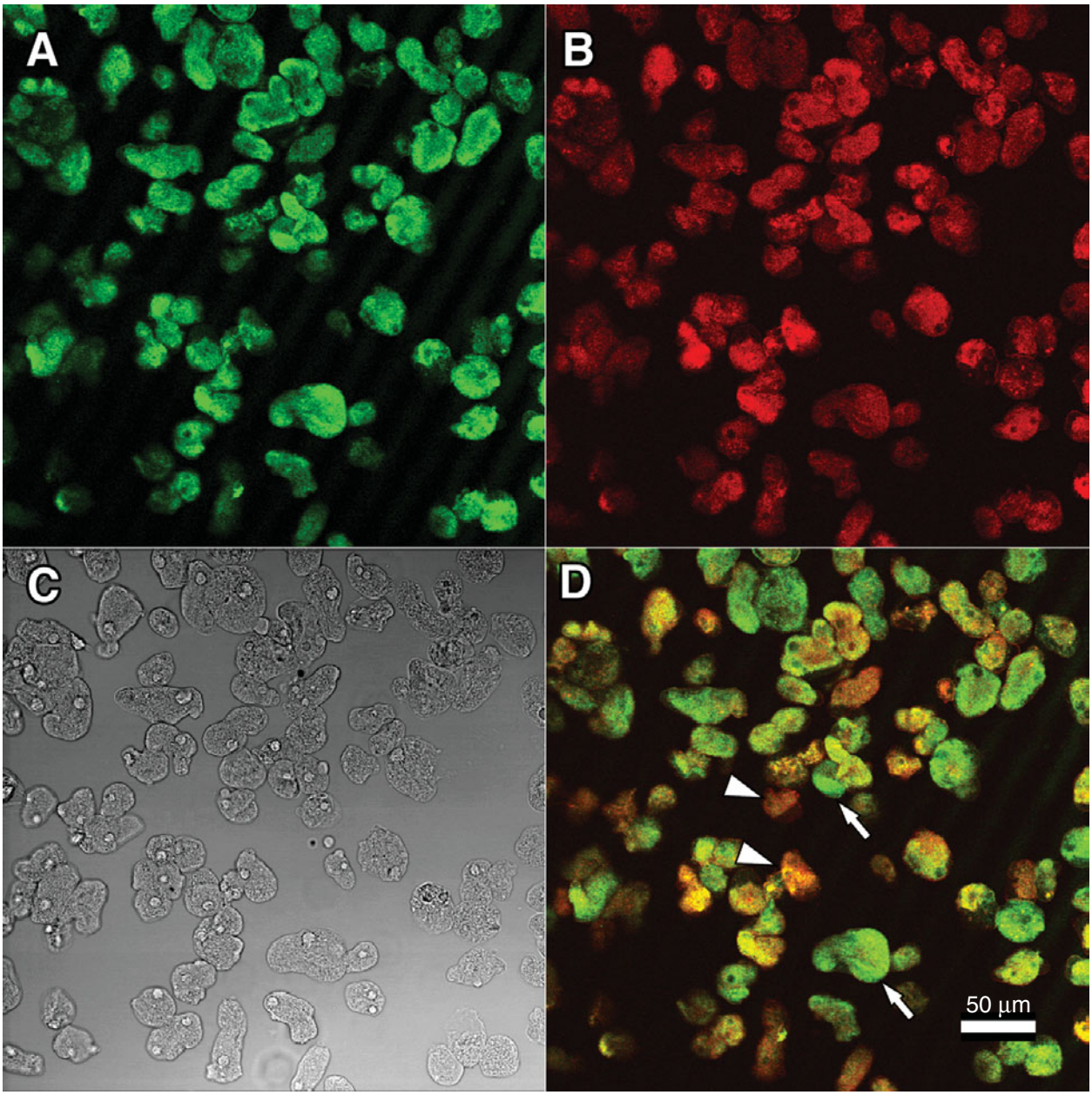

Fig. 6. Localization of Igl1 and Igl2 on trophozoites of *Entamoeba dispar* SAW1734RclAR observed by confocal laser scanning microscopy. Fixed trophozoites were stained with ED1-13 specific for Igl1 and a secondary Alexa Fluor 488-labelled anti-mouse IgG2b antibody (green) (A) or ED2-1 specific for Igl2 and a secondary Alexa Fluor 594-labelled anti-mouse IgG1 antibody (red) (B). Differential interference contrast microscopy is shown in (C). A merged image is shown in (D). Arrows and arrowheads indicate Igl1- and Igl2-dominant cells, respectively.

One of the interesting observations in this study is the difference in expression between Igl1 and Igl2. Since higher expression of Igl1 was observed at both protein and mRNA levels, the difference between the isoforms seems to be regulated mostly at the transcriptional level. The expression level of *Igl1* was also lower in *E. dispar* than in *E. histolytica*, whereas that of *Igl2* was comparable in the two species. It has been demonstrated that expression of *Hgl* (*Hgl2*) and *Lgl* (*Lgl1*) in *E. dispar* is lower than in *E. histolytica* (Pillai *et al*. 1997, 2001); therefore, Igl1 may be more closely associated with Hgl and Lgl. However, it is unknown whether the 2 Igl isoforms are associated with different isoforms of Hgl or Lgl. DNA microarray analyses have shown that a large number of genes are expressed differently in *E. histolytica* and *E. dispar*, and that there is a difference in gene expression between strains of *E. histolytica* of high and low virulence (Shah *et al*. 2005; MacFarlane and Singh, 2006; Davis *et al*. 2007). Lower expression of *Hgl* genes in *E. dispar* compared to *E. histolytica* has also been confirmed (MacFarlane and Singh, 2006), but *Lgl3* expression was found to be higher in an *E. histolytica* strain of low virulence compared to a strain of high virulence (Davis *et al*. 2007). *Igl* genes are down-regulated by

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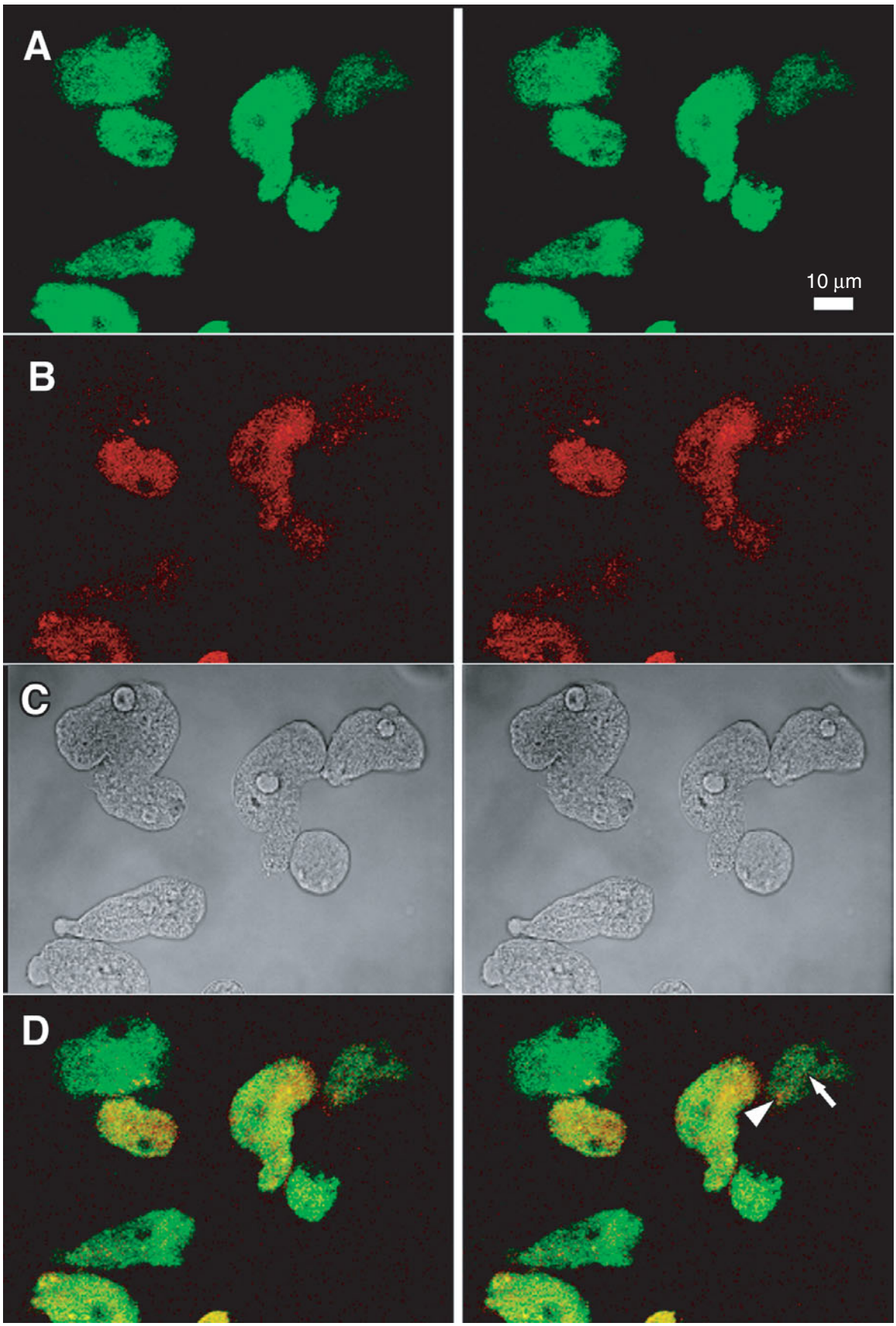

Fig. 7. Stereo images of localization of Igl1 (A) and Igl2 (B) on *Entamoeba dispar* trophozoites observed by confocal laser scanning microscopy. Fixed trophozoites were stained as described in Fig. 6. Differential interference contrast microscopy is shown in (C). A merged image is shown in (D). Arrow and arrowhead indicate single localization of Igl1 and Igl2, respectively.

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heat shock stress, as are most *Hgl* and *Lgl* genes (Weber *et al*. 2006). Collectively, these observations suggest that the lectin as a whole is important for adherence and subsequent pathogenesis.

We also compared phenotypic expression of the two Igls in each trophozoite using flow cytometry and confocal microscopy. Interestingly, some trophozoites expressed Igl1 or Igl2 dominantly, although most cells expressed the two Igl proteins to a comparable extent, suggesting that both Igls are important for the amoeba. Igls were also localized in intracellular vacuoles of *E. dispar*. Recently, it has been demonstrated that Igl is contained in phagosomes of *E. histolytica* and that the quantity of Igl varies during phagosome maturation (Okada *et al*. 2005, 2006). The different localization of Igl1 and Igl2 in vacuoles suggests that the functions of the two Igls may differ or that their expression may vary during maturation of phagosomes or depending on certain cellular conditions. However, there may also be differences in the involvement of microtubules and proteases in phagosome maturation and degradation in *E. histolytica* and *E. dispar* (Mitra *et al*. 2005). In *E. histolytica*, different subcellular localization of the two Igl isoforms has yet to be shown.

In conclusion, this is the first study of the differences between Igl1 and Igl2 of *E. dispar*. Igl seems to be a vaccine candidate for amebiasis and may also be a useful antigenic molecule for specific serodiagnosis of amoebiasis (Cheng and Tachibana, 2001; Tachibana *et al*. 2004). Therefore, further studies of Igl are required to clarify its role in the host-parasite relationship.

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