Polynadviruses are symbiotic viruses associated with some parasitic wasps from the ichneumonid and braconid families. They are maintained in the wasp population by stable integration of proviral DNA in the wasp genome (Stoltz et al., 1986; Fleming & Summers, 1991). Unique among the viruses, they require two distinct insect hosts to achieve their complete life-cycle. Replication occurs solely in the calyx epithelial cells of the female wasp oviduct leading to an encapsidated viral genome composed of several circular molecules of double-stranded DNA in a non-equimolar ratio. The viral particles accumulate in the female oviducts and are injected during parasitization into a lepidopteran egg. In the lepidoptera, infection of different tissues leads to expression of a host-specific subset of viral genes. Viral gene expression is mandatory for parasitoid survival and development by inducing physiological alterations in the lepidopteran host (reviewed by Webb, 1998).

During replication, viral DNA is excised from the wasp genome then packaged into virions. Recent data obtained in braconids suggest that amplification of viral DNA precedes circularization (Marti et al., 2003; Pasquier-Barre et al., 2002). The mechanisms of polynadivirus replication are as yet unknown and represent a puzzling mystery for virologists. Replication is tissue-specific and development-dependent as it occurs solely in specialized cells of the female wasp oviduct and is first detected at the end of pupal development (Norton & Vinson, 1983; Volkoff et al., 1995). The regulation of virus replication is probably related to the calyx cell differentiation and is thus indirectly related to the biologically active derivatives of the insect hormone ecdysone, 20-hydroxyecdysone (20HE) (Marti et al., 2003; Webb & Summers, 1992). In addressing the question of polynadivirus replication, researchers have to date been limited by the impossibility of promoting in vitro replication and a lack of appropriate tools (Stoltz, 1993). In this work, we describe cell lines that were established from *Hyposoter didymator* pupae. *H. didymator* is an ichneumonid wasp associated with the polynadivirus *H. didymator* ichnovirus (HdIV). These cell lines are, to our knowledge, the first to be derived from a polynadivirus-associated wasp and may constitute a valuable tool for future investigations on polynadivirus replication.

The cell lines were established from young *H. didymator* pupae (0–24 h after meconium release). Cocoons were washed in 20% bleach solution, then rinsed twice with sterile water. Pupae of both sexes were recovered and washed rapidly in 5% bleach, then rinsed twice with sterile water. The dissected pupae were stored in HdM cell culture medium until a sufficient amount of material had been collected (20–25 pupae). HdM is composed of TC100 modified medium (Gibco) supplemented with 20% foetal calf serum (Gibco), 1% G5 complement (Gibco), 4% *Kniphoia* nectar (Pronectar SA), 1·61 g putrescine 1−1 (Sigma), 50 units nystatin ml−1 (Sigma) and 1·25 μg fungizone ml−1 (Gibco). Pupae were then placed in a Petri dish, rinsed with sterile PBS, and cut into small pieces with two scalpel blades. The lacerated samples were dissociated...
Fig. 1. Control of wasp origin of the established cell lines. (A) Position of the primers F18S and R18S in conserved regions of the 18S rDNA used for PCR amplification. (B) HindIII digest of the obtained PCR products, after separation by agarose gel electrophoresis and ethidium bromide staining. Molecular masses are indicated on the left. Templates were H. didymator pre-pupae (pP) and the Hd cells (AD, AA, K and BBA). Arrows indicate the two restriction fragments. (C) ClustalX alignment of the sequences of the PCR products obtained from the Hd-AA cell line (Hdcell; GenBank AY433942) and the S12b cell line (C. Pelle, S. Gimenez & P. Fournier, unpublished) showing the nucleotides that differ between the two sequences. Primer sequences are indicated by arrows and the region containing the hymenoptera-specific HindIII restriction site is boxed.
either by incubation in trypsin/EDTA solution (2·0 mg trypsin ml⁻¹, 0·08 M EDTA) for 1 min or by incubation in collagenase solution (0·5 mg ml⁻¹) for 2 min. Samples were washed twice by centrifugation (5 min, 1000 r.p.m.), resuspended in 3 ml HdM and placed in a 12·5 cm² flask (Falcon) at 28 °C. The culture medium was replaced by fresh HdM or HdM₀ [containing 0·5% G5 complement] the following day and then periodically until establishment of the cell lines. After about 2 years, four different cell lines, named Hd-AA, -AD, -BBA and -K, were established. The AA and AD cell lines were established following incubation in trypsin/EDTA solution. AA cells were kept in HdM₀, while AD cells were maintained in HdM. The BBA and K cell lines were established following incubation in collagenase solution. BBA cells were kept in HdM, whereas K cells were maintained in HdM₀.

To control the wasp origin of the cell lines and discard the possible risk of contamination by the lepidopteran host Spodoptera littoralis cells, 18S rDNA sequences from the Hd cells, H. didymator pre-pupae and S. littoralis cells and eggs were PCR amplified and analysed. Primers F18SHd (5’-GACTGACGTCCAGAATGCTGGTGCCAGCAG-3’) and R18SHd (5’-CATGGAATTCTGGTGCCCTTCCGTCATACT-3’) were designed in conserved regions flanking a HindIII restriction site predicted to be conserved in the amplified hymenopteran sequences, but absent in the lepidopteran ones. As predicted, all the PCR products. Indeed, rDNA from the four cell lines was extracted from wasp pre-pupae and S. littoralis eggs. According to sequences available in GenBank from other insects, a HindIII restriction site was predicted to be conserved in the amplified hymenopteran sequences, but absent in the lepidopteran ones. As predicted, all the amplification products from H. didymator cells and insects were digested by this enzyme (Fig. 1B) but none from Spodoptera (data not shown). The wasp origin of the established cell lines was confirmed by sequencing of the PCR products. Indeed, rDNA from the four cell lines was found to be different from the S. littoralis sequence (Fig. 1C) and identical to the wasp pupae rDNA (data not shown).

The four Hd cell lines could be differentiated by their general morphology (Fig. 2), suggesting they differed with regard to their genetic/phenotypic background. Cells were observed by light and electron microscopy. For electron microscopy, cells were pelleted by centrifugation (5000 g, 10 min), then fixed and observed as previously described (Volkoff et al., 1995). The AA and K cells were isolated cells but tended to form aggregates. The AA cell population was mainly composed of fusiform cells, whereas the K cells were star-shaped cells in contact with each other via well-developed pseudopodia. Their doubling time was, respectively, 2 and 4 days. The two other cell lines, AD and BBA, showed more evident intercellular junctions. The BBA cells were small round cells that grew very slowly (doubling time of 8 days). The AD cells (with a doubling time of 4 days) were characterized by a large nucleus. The latter were strongly adherent to the substrate and grew in a cohesive monolayer. Interestingly, early after establishment (8th passage), the AD cell line, when submitted to 20HE treatment, formed organized tissue-like structures (Fig. 2). However, 3 years later (~107th passage), 20HE treatment induced no more differences in cell morphology.

For karyotype observations, cells were seeded for 24 h on to microscope coverslips and treated with 1·5 μg colcemid ml⁻¹ for 7 h. Fixation, DAPI staining and observations were performed as previously described (Gerbal et al., 2000). In the Hd cells, the chromosome number was significantly higher than that found in the haplo-diploid insect (n=12, data not shown). It generally varied from 3n to 5n, depending on the cell line (Fig. 2); the most variable population was found in the AA cell line, where some cells contained up to 10n chromosomes. This increase in chromosome number linked to cell line establishment was not surprising and has been previously reported for other cell lines (Gerbal et al., 2000).

As the HdIV genome was predicted to be integrated in the wasp chromosomes, Southern blot analysis was performed to analyse the HdIV DNA status in the four cell lines. The procedure employed for hybridization was as described by Volkoff et al. (1999). The probe consisted of [α-32P]dCTP-labelled (Nick-translation kit; Roche) total viral DNA. The results indicated that the HdIV DNA probe hybridized with the AA, AD, BBA and K cell genomic DNA, while no hybridization was observed with the lepidopteran cell samples (Fig. 3A). No circular viral DNA, as observed in encapsidated virus (Fig. 3A, lane HdIV), could be detected in the cell lines. The hybridization signal co-localized with high molecular mass DNA, suggesting integration of the viral DNA into the wasp cell chromosomes.

Interestingly, some viral transcripts were detected in the AA cells when mRNA was probed with total HdIV DNA, but at very low level compared with HdIV-infected Sf9 cells (Fig. 3B, compare lanes C and Sf+V). We do not know if the low level of gene expression observed in the AA cells has a biological significance. It could be related to the existence of low amounts of excised DNA in the wasp cells, which has been described in non-calyx cells of other wasps (Savary et al., 1999), despite the fact that we could not detect this by Southern blotting (Fig. 3 A and D). In the wasp, the virus particles stored in the oviduct have never been reported to infect the insect cells, which could be due to a mechanical barrier or another unknown mechanism. Nevertheless, HdIV particles may enter wasp cells (Fig. 3C) when the latter are infected in vitro [infections were conducted as described by Volkoff et al. (1999) using 40 H. didymator females per ~10⁶ cells for 4 h]. When transcripts were analysed in the infected AA cell
Fig. 2. Morphology of the *Hyposoter didymator* cell lines AA, AD, K and BBA. Left panels shows phase-contrast observations. AA panel: the arrowhead indicates a fusiform cell; the arrow indicates two spherical cells. K panel: arrow indicates a pseudopodium connecting two cells. AD panel, insert: tissue-like structure observed by phase-contrast microscopy 48 h after 20HE treatment (10⁻⁷ mg ml⁻¹). Right panels show transmission electron microscopy views. The nucleus (N) and cytoplasm (C) are indicated. In the AD and BBA panels, arrowheads indicate cell–cell junctions; in the K panel, ps indicates a pseudopodium. Bar, 1 μm. In the AA and K cell panels, DAPI-stained chromosomes are shown indicating the polyploidization of the cells in culture (˃5n for AA cells and 3n for K cells).

Fig. 3. Polydnaviral DNA and RNA status in the wasp cell lines. (A) Southern blot analysis of the Hd cell lines. DNA was extracted from the lepidopteran cell lines Sf9 and SL2b and from the wasp cell lines AA (80th passage), BBA (51st passage), AD (78th passage) and K (38th passage) according to a standard protocol (Ausubel et al., 1995). Approximately 20 μg of each sample and 5 μg of control viral DNA (HdIV) were separated by electrophoresis on a 0.8% TAE agarose gel. (B) Northern blot analysis of the AA cell line. Total RNA was extracted from uninfected and HdIV-infected Sf9 (Sf-C and Sf+V, respectively) and AA cells (C and +V, respectively) and from 42 °C heat-shocked AA cells (101st passage). In vitro cell infections (+V) were conducted for 4 h and samples were analysed 40 h post-infection. Heat-shocked cells were treated for 1 or 2 h (T1 and T2, respectively) and analysed 24 h after treatment. Approximately 15 μg mRNA was loaded per sample. The film was exposed for 48 h for lanes Sf+V and Sf-C and for 15 days for the others. (C) HdIV infection of K cells observed by transmission electron microscopy: an HdIV particle is entering the cell by endocytosis (arrow); another (arrowhead) is in the cell cytoplasm (C); N indicates the cell nucleus. (D) Southern blot analysis of the AA cell line. DNAs were extracted from uninfected and HdIV-infected Sf9 (Sf-C and Sf+V, respectively) and AA cells (C and +V, respectively) and from 42 °C heat-shocked AA cells (101st passage). In vitro cell infection and heat-shock treatment were as described in (B). Samples E-6 and E-7 were treated with two concentrations of 20-hydroxyecdysone [10⁻⁶ and 10⁻⁷ mg (ml solution)⁻¹; respectively] for 48 h and analysed 24 h after treatment. Electrophoresis was carried out as in (A). For all blot analysis, the probe consisted of [α-³²P]dCTP-labelled total HdIV DNA. Molecular masses (kbp) are indicated on the left.
lines by Northern blotting, using labelled HdIV DNA as a probe, no difference was found compared with non-infected cells (Fig. 3B, compare lanes + V and C). This may indicate that only a small number of HdIV particles infect Hd cells or that Hd cells lack factors allowing virus expression, as is the case with lepidopteran cells. When DNA status was analysed in HdIV-infected AA cells, no circular viral DNA could be detected (Fig. 3D, lane +V), suggesting the absence of excision/circularization of viral DNA in these cells. A quantitative analysis will nevertheless be necessary to determine whether DNA amplification is taking place within the wasp chromosomes.

Since 20HE is known to be related to polydnavirus replication, the AA cell line was submitted to increasing concentrations of 20HE and analysed by Southern and Northern blotting. Treatment was found to be deleterious, with concentrations of 20HE and analysed by Southern and Northern blotting. Since 20HE is known to be related to polydnavirus replication, the wasp chromosomes.

Thus, neither 20HE treatment, HdIV infection, nor 42°C heat-shock applied to the AA cell line promoted virus replication, at least at a level detectable with the currently available tools, in the wasp cells in culture. It should be noted that sequencing data now available on several polydnavirus genomes indicate that encapsidated genomes encode few genes related to virus replication (Turnbull & Webb, 2002). Therefore, because the probe used consisted of the HdIV encapsidated genome, we cannot exclude the possibility that other genes (non-encapsidated viral genes, if they exist, or wasp cellular genes) that may be involved in virus replication are transcribed but not detected in the AA cells. Furthermore, as mentioned by Webb & Summers (1992), there are probably many factors involved in the regulation of polydnavirus replication, such as sex, developmental and tissue-specific factors, that are yet to be identified.

To conclude, the H. didymator cell lines described in this work are some of the few established from hymenoptera insects. They contain a polydnavirus genome and should be a valuable tool to study the status of polydnavirus genomes in their wasp hosts and to analyse various factors that may lead to HdIV replication. Having these cell lines available thus offers great potential to understand better the still mysterious polydnavirus organization and life-cycle.

Acknowledgements

The authors are very grateful to Don Stoltz and Philippe Fournier for their comments on the manuscript. We also would like to thank Bertrand Limier for his help with the H. didymator colony and Simone Berger for her technical assistance.

References


