Abstract. A temperature-sensitive mutation in the nudC gene (nudC3) of Aspergillus nidulans specifically prevents the microtubule-based movement of nuclei in this organism at the restrictive temperature. The mutation does not affect short term growth, nuclear division, or the movement of other subcellular organelles. Immunofluorescence analysis of cells blocked at the restrictive temperature, using antitubulin antibodies, shows that the inability of nuclei to move under these conditions is not related to an inability of a particular class of microtubule to form. The inability to move nuclei in this mutant is also shown to be independent of both mitosis and the number of nuclei in the cell as a double mutant carrying both nudC3 and a cell cycle-specific mutation blocks with a single immotile nucleus at the restrictive temperature. The molecular cloning of the nudC gene and sequence analysis reveal that it encodes a previously unidentified protein of 22 kD. Affinity-purified antisera reactive to the nudC protein cross reacts to a single protein of 22 kD in Aspergillus protein extracts. This purified sera failed to reveal a subcellular location for the nudC protein at the level of indirect immunofluorescence. The data presented suggest that the 22-kD nudC gene product functions by interacting between microtubules and nuclei and/or is involved in the generation of force used to move nuclei during interphase.
nuclear movement has been shown to require beta-tubulin function in *Aspergillus*; Oakley and Morris, 1980, 1981), or be part of an intracellular signaling system that specifies nuclear movement should occur. The molecular cloning of the *nud* genes, as well as genes that interact with them, and a functional analysis of their products will help lead to an understanding of the molecular mechanisms of nuclear movement.

The most obvious manner by which the *nud* mutations could render microtubule-based nuclear motility inoperative would be to cause the selective loss of a particular type of microtubule population that is specifically required for nuclear movement, for example, cytoplasmic microtubules or astral microtubules, at the restrictive temperature. We have therefore carried out an immunofluorescence study to determine if the *nud* phenotype of the nudC3 mutation is caused by the loss of a particular subpopulation of microtubules. We have also investigated the dependence of the *nud* phenotype on the completion of mitosis. In addition we describe the cloning of the nudC gene by complementation of the mutant phenotype using a genomic plasmid library. The sequence of several cDNA clones of the gene and the genomic clone reveal that the nudC gene encodes a previously unknown 22-kD protein. Finally, affinity-purified antibodies reactive to the nudC gene product have been produced and used to identify this previously unknown protein.

**Materials and Methods**

**Aspergillus Strains and Growth**

The strains used in this study were AO1 (nudC3, wA2, nicA2, pobaA1, pyrG89), AO2 (nudC3, nimA5, ykA2, and possibly other markers from SO14), SO1 (nimA5, wA2), and SO14 (nimA5, riboA2, nicB8, ykA2). The permissive temperature for growth was 25°C and the restrictive temperature 42°C using YAG media (0.5% yeast extract, 2% glucose, trace elements, PO4, pH 6.5, 0.02 μg/ml 4'6-diamido-2-phenylindole (DAPI) and viewed under epifluorescence as described previously (Bergen et al., 1984). The matrix was washed extensively with TBS before elution of the antibodies using 100 mM glycine, pH 2.8. Fractions were collected into sufficient 1 M Tris, pH 8.0, to neutralize the glycine, and those fractions with significant adsorption at 280 nm were dialyzed against TBS.

**Staining Techniques and Microscopy for Aspergillus nidulans**

To visualize DNA-containing organelles, cells were fixed in a solution containing 16% Glyceral, 4% Glutaraldehyde, 0.16% Triton-X100, 40 μm PO4, pH 6.5, 0.002 g/ml 4',6'-diamido-2-phenylindole (DAPI) and viewed under epifluorescence as described previously (Osmani et al., 1988a). Indirect immunofluorescence of Aspergillus nidulans was carried out as described previously (Osmani et al., 1988a).

**Molecular Cloning of the nudC Gene**

The temperature sensitivity and uridine requirement of strain AO1 were complemented by DNA-mediated transformation using the plasmid library and techniques as described in Osmani et al. (1987). DNA from such doubly complemented transformants was analyzed by Southern blotting using nick-translated vector DNA (May et al., 1985) as a probe to identify those transformants containing a single site of plasmid integration in their genome. Plasmids from such a transformant were obtained from genomic transformants containing a single site of plasmid integration in their genome. Plasmids from such a transformant were obtained from genomic transformants containing a single site of plasmid integration in their genome. A cDNA library constructed from *Aspergillus nidulans* total polyA+ mRNA as described previously (Osmani et al., 1988a). The smallest genomic fragment able to complement nudC3 was sequenced on both stands as were the nudC cDNAs using the dideoxynucleotide chain termination procedure (Sanger et al., 1977).

**Production and Affinity Purification of Anti-nudC Antisera**

To raise antibodies to the product of the nudC gene we subcloned a 633-bp Aul fragment from nudC cDNA into the Sma I site of the pATH11 vector to produce a fusion protein between nudC and the amino terminus of *E. coli* ribulosephorases (Crivellone et al., 1988). The fusion protein was induced and isolated in an insoluble fraction before final purification by preparative SDS-polyacrylamide electrophoresis (Crivellone et al., 1988). 250 μg of the purified fusion protein in Freund's complete adjuvant was used to immunize guinea pigs which were then boosted at 10-d intervals with 100 μg of antigen in incomplete adjuvant. Blood was collected at 2-wk intervals by heart puncture and the isolated sera tested for reactivity to total Aspergillus nidulans protein by Western blotting (Towbin et al., 1979). Affinity purification was carried out on positive sera by reacting the sera to the fusion protein that had been cross linked to Affi-Gel according to the manufacturer's instructions (Bio-Rad Laboratories, Richmond, California). After binding, the matrix was washed extensively with TBS before elution of the antibodies using 100 mM glycine, pH 2.8. Fractions were collected into sufficient 1 M Tris, pH 8.0, to neutralize the glycine, and those fractions with significant adsorption at 280 nm were dialyzed against TBS.

**Results**

**The nudC Gene Function Is Specifically Required for Nuclear Migration**

If conidia (unicellular asexual spores of *Aspergillus* are inoculated into growth medium they germinate and send out a germ tube. The single nucleus present in the conidia normally undergoes a division before the germ tube has grown and the nuclei migrate into the growing germ tube as it begins to emerge. Subsequent nuclear divisions occur as the cell grows at the tip of the germ tube, and the resulting nuclei are maintained at a fairly constant distance from one another in the growing mycelial tube. Strains carrying the nudC3 mutation are specifically temperature sensitive for the process that normally moves nuclei into the germ tube and maintains nuclei at a distinctive distance from one another during growth. The phenotype is best visualized by comparing nuclear movement during germination of wild type conidia (Fig. 1, left panel) to nudC3 carrying conidia (Fig. 1, right panel) when both are germinated at the restrictive temperature (Fig. 1). The nuclei in the wild type strain shown in Fig. 1 (left panels) have undergone four divisions. The resulting nuclei are maintained at regular intervals in the growing germ tube. In the strain carrying nudC3 it can be seen that this mutation does not prevent the short term processes of germination, cellular growth, or mitosis, and the mutant cells in Fig. 1 (right panel) have also undergone four nuclear divisions. However, in these mutant cells, the resulting nuclei are unable to move into the germ tube. Upon prolonged incubation, cellular growth in nudC3 mutants does become inhibited at the restrictive temperature and very restricted colonies are eventually formed that are unable to undergo the normal program of differentiation to form conidia (data not shown).

**Does the nudC3 Mutation Affect a Particular Class of Microtubule?**

The movement of nuclei in *Aspergillus* has been shown to be
dependent on a functional microtubule system (Oakley and Morris, 1980, 1981). We have therefore studied the appearance of microtubule cytoarchitecture in a nudC3 strain grown at the restrictive temperature to determine if the inability to move nuclei under these conditions is related to any gross defects in, or absence of, a particular microtubule structure.

A strain carrying the nudC3 mutation was germinated at the restrictive temperature and stained with DAPI and anti-tubulin antibodies by indirect immunofluorescence to visualize both microtubules and the position of nuclear DNA (Fig. 2). The DAPI staining pattern of these cells showed that nuclear division could take place but that the resulting nuclei remained in the germ tube head (Fig. 2, right panel) demonstrating that the nud phenotype was being expressed.

We then studied the samples to ascertain if these mutant cells were able to form cytoplasmic microtubules, mitotic spindles, and astral microtubules. A cytoplasmic network of microtubules was apparent throughout cells during interphase (three germlings to the far left of Fig. 2). The pattern of staining during interphase was indistinguishable from that of wild type cells (data not shown, see Osmani et al., 1988a; Engle et al., 1988; Doonan and Morris, 1989) indicating that cytoplasmic microtubules could form in the nudC3 mutant at restrictive temperature.

At mitosis spindles were observed to form in the bulb of germlings (Fig. 2, arrowhead) and in the mitotic cells cytoplasmic microtubules were largely disassembled (Fig. 2, arrowed cell) in a manner similar to wild type cells at mitosis. Therefore, the microtubule cycle (from cytoplasmic microtubules to spindle and back to cytoplasmic microtubules) does not appear to be affected by the nudC3 mutation nor is there an inability to form mitotic spindles and undergo nuclear division.

We also studied mitotic cells for the presence of the astral microtubules normally associated with the spindle pole bodies of Aspergillus during part of mitosis. The cell depicted in Fig. 3 can be seen to have sent out three germ tubes with the result that the spindles present in the cell are spread out and the astral microtubules can be clearly seen (Fig. 3, arrows) demonstrating that this third class of microtubule structure can form in this mutant at the restrictive temperature.

The above data demonstrate that the nudC3 mutant phenotype is not caused by a major defect in tubulin assembly into any identifiable class of microtubule structure (cytoplasmic, spindle, or astral), the absence of which could affect nuclear migration.

**Is the nudC3 Mutant Phenotype Dependent on Mitosis?**

During the process of spore germination one mitosis normally occurs before germ tube extension. It is possible that the presence of two nuclei in the swollen spore before germ tube extension could play a role in hindering normal nuclear migration in the nud mutants and hence contribute to the nud phenotype. For example, stearic hindrance could be a factor if nuclei could not separate correctly at the end of mitosis in the nudC3 mutant cells. In addition, as it is known that significant nuclear movement is normally associated with mitosis in Aspergillus, particularly during telophase (Gambino et al., 1984), we were interested to ascertain if absence of nuclear division would modify the nudC3 mutant phenotype. To this end we constructed a double mutant strain carrying both the nudC3 mutation and the temperature-sensitive nimA5 mutation. The nimA5 mutation causes a G2 block at the restrictive temperature (Oakley and Morris, 1983; Bengen et al., 1984). By germinating conidia of the nudC3, nimA5 double mutant at the restrictive temperature we have asked whether a single nucleus in a germinated cell is able to move into the germ tube when the nudC3 mutation is imposed. If conidia of a nimA5 mutant strain are grown at the restrictive temperature for a period to allow germ tube extension, the single nucleus present in the cell is able to move into the growing germ tube (Fig. 4). The double nimA5, nudC3 mutant strain also has a single nucleus but in this case the nucleus is not able to migrate into the germ tube (Fig. 4).

These data demonstrate that the nudC3 mutant phenotype (inability to move nuclei) is independent both of mitosis and the number of nuclei present in the germling before germ tube extension.

**Molecular Cloning of the nudC Gene**

We have cloned the nudC gene by DNA-mediated complementation of the nudC3 mutant phenotype using techniques outlined previously (Osmani et al., 1987). The mutant nudC3 ts" mutation was complemented by integrative transformation using a genomic plasmid library (Osmani et al., 1987) in a vector that contains the pyr4 gene of Neurospora which is able to complement the pyrG89 mutation of Aspergillus (Ballance et al., 1983). Several transformants were identified that were no longer temperature sensitive for growth. Because the transformants could reflect either integration of wild type nudC sequence or a suppressor of nudC3, the transformants were analyzed by the two step gene replacement method (Miller et al., 1985). Several temperature-resistant nudC3 transformants were shown by Southern blot analysis to contain a single integrated copy of the transforming plasmid. One of these transformants was put through a self cross to replace the endogenous genomic sequence with the integrated wild type sequence. Because site-specific integration creates a tandem duplication of the target sequence with one wild type and one mutant copy, when a site-specific transformant is put through a genetic cross with itself, the tandem sequences recombine in 5–10% of the progeny to eliminate either the wild type or the mutant nudC3 sequence and the intervening pyr4 containing plasmid sequence. Temperature-resistant pyr4" progeny from the self cross that contained the wild type sequence were identified, and these were crossed to a wild type strain to determine whether integration was at the nudC locus or some other (suppressor) locus. If the gene replacement occurred at the nudC locus, a cross back to a wild type strain should not reveal any ts" progeny. If, on the other hand, a suppressor had been gene replaced, a cross back to wild type should uncover the original ts" mutation. In five gene-replaced strains crossed back to a wild type strain we found no ts" progeny from a total of 278 progeny tested. We therefore conclude that we had complemented the ts" phenotype with the wild type copy of the nudC gene and not a suppressor.

Plasmids were recovered from the nudC" transformant described above by partial restriction digestion of genomic DNA followed by ligation and transformation of E. coli to ampicillin resistance. A common fragment from the isolated
plasmids was used to probe a lambda Charon 4A genomic library. Six Eco RI fragments from the resulting genomic clones were tested for their ability to complement the nudC3 mutation, and a 6.4-kb fragment was identified that contained this activity (Fig. 5). Subcloning experiments were performed on this genomic Eco RI fragment and an analysis of these data is given in Fig. 5. The results demonstrate that the Eco RI-Acc I fragment C is capable of complementing the nudC3 mutation and that it hybridizes to a RNA species of ~850 bases.

**Sequence Analysis of the nudC Gene**

Fragment C was used as a specific probe for the nudC gene to probe an Aspergillus cDNA library (Osmani et al., 1988b) to isolate cDNA copies of the gene for sequence analysis. Four different nudC cDNAs were isolated, ranging in size from 333 to 826 bp. The larger cDNAs were subcloned into a pUC plasmid vector and tested in transformation experiments for their ability to complement the nudC3 mutant phenotype relying on gene conversion to correct the nudC3

**Figure 1.** The effect of the nudC3 mutation on nuclear migration in germlings of Aspergillus nidulans. The series on the left show a wild type strain and the series to the right a strain carrying the nudC3 mutation. Growth of conidia (asexual uninucleate spores) was at the restrictive temperature of 42°C and nuclei have been visualized by staining with the DNA-specific dye DAPI. The temperature of growth has no effect on nuclear motility in the wild type strain but has severely restricted nuclear migration in the nudC3 strain. Bar, 5 \( \mu m \).
mutation. These were found to be able to complement the nudC3 mutation, confirming they contain the nudC gene. Initial sequence data showed that all the cDNAs were of a common origin, the nudC locus, and were derived from within a single Hind III fragment. Sequence analysis was performed on this Hind III fragment to obtain the genomic sequence of the gene and all four cDNAs were sequenced to derive the nudC translational unit (Fig. 6).

A comparison of the nudC cDNA sequences to that of the genomic reveals that there are two introns present (Fig. 6). Interestingly, one of the cDNAs isolated did not have these introns spliced out, leading to the formal possibility that the nudC gene encodes two different proteins based on differential splicing (but see below).

Theoretical translation of the cDNA that extended furthest to the 5' end identified an open reading frame initiating at the first ATG present in the sequence after 76 nucleotides. This open reading frame is preceded by a stop codon and is open for 198 codons and could encode a protein of 22.4 kD (Fig. 6). Translation of the cDNA derived from unspliced mRNA could potentially initiate at this same codon. This reading frame is maintained through the first intron, which would introduce an extra 21 amino acids. The reading frame is continued through the second exon and remains open into the second intron. After translation of 24 amino acids encoded in the second intron the reading frame terminates. This second potential protein would contain 233 amino acids and have a computed molecular weight of 26 kD.

**Identification of the nudC Gene Product in Aspergillus**

A fusion protein between the trpE gene of *E. coli* and a portion of the nudC gene was produced in *E. coli* and purified to use as antigen to raise a polyclonal antiserum against the nudC gene product (see Materials and Methods). This sera,

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**Figure 4.** Absence of nuclear division does not affect the nud phenotype of nudC3. Conidia of a strain containing the nimA5 mutation (left panel) and a double nimA5 nudC3 mutant (right panel) were germinated at the restrictive temperature of 42°C and stained with DAPI to visualize the number and position of nuclei. Bar, 5 μm.
when reacted to *Aspergillus* protein, identified a protein of some 22 kD and a high molecular weight smear on Western blots. The preimmune sera did not react with the 22-kD protein nor with the smear. We affinity purified the immune sera against the primary antigen. This purified sera only reacted with the 22-kD protein, and the wash through from the affinity column reacted with the high molecular weight smear (Fig. 7). These data indicate that the unspliced mRNA, detected by the isolation of genomic sequence containing cDNA, does not get translated in vivo because, if it did, one would expect to detect a second protein significantly larger than 22 kD, at 26 kD. Therefore, because the high molecular weight material detected by the immune sera is not reactive in the affinity-purified sera, and because the molecular weight of the reactive protein to the affinity-purified antibody is that predicted from the sequence analysis, we think it most likely that the 22-kD protein represents the only protein product of the *nudC* gene. However, there is a formal possibility that a second protein is produced from *nudC* at a level below our detection limits.

Preliminary immunofluorescence studies to localize the *nudC* gene product in actively growing germlings using the affinity-purified *nudC* specific antisera did not identify a particular subcellular location for the *nudC* gene product.

**Discussion**

In the present work we have tested the hypothesis that the
temperature-sensitive nudC3 mutation of Aspergillus disrupts the microtubule-based motility system responsible for nuclear movement in this organism by selectively destroying a particular class of microtubule. The results indicate that this notion is not correct as all three classes of microtubules visible by indirect immunofluorescence (spindle, cytoplasmic, astral) could be readily detected in cells carrying the nudC3 mutation when they were grown at the restrictive temperature and unable to move nuclei. We conclude that the molecular defect caused by the nudC3 mutation that leads to an inability to transport nuclei is not associated with the loss of a particular class of microtubule. During the course of this work a similar conclusion has been reached, using EM, for another Aspergillus nidulans nud mutation, nudB2 (Mayer et al., 1988).

We have also determined the effect of preventing nuclear division on the nud phenotype caused by the nudC3 mutation by constructing a double mutant between nudC3 and another temperature-sensitive mutation that causes a cell cycle–specific block at the restrictive temperature. The phenotype of the double mutant at the restrictive temperature is a nud phenotype in a cell containing a single division-blocked nucleus. This result clearly demonstrates that the nudC3 mutant phenotype is independent of both mitosis and the number of nuclei present in the cell.

If the nudC gene product does not affect the structural integrity of microtubules or disrupt mitosis, how else might it function? Since actin, tubulin, and a kinesin-related protein have all been implicated to play a role in nuclear movement (Lloyd et al., 1987; Schatten et al., 1986), it could be a protein that interacts with, or regulates the activity of, one of these proteins. Although we know from its predicted amino acid sequence and from Western blots with antibody generated against a nudC fusion protein that the gene encodes a protein of 22 kD, comparison of the nudC protein sequence to known sequences in the standard databases has not provided any clues about the identity or activity of nudC. We do, however, now know that the nudC gene product is a newly discovered protein that plays a role in nuclear migration in addition to the already known proteins actin, tubulin, and kinesin. How, or if, the nudC gene product interacts with these other components will be the focus of future studies.

Elucidation of the function of the gene products defined by the unique nud mutations of Aspergillus should shed considerable light on the molecular mechanisms by which eukaryotes normally move nuclei and possibly cytoplasmic motility in general. The cloning and sequence of nudC is the first step towards this analysis.

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References

Ballance, D. F., F. P. Buxton, and G. Turner. 1983. Transformation of Aspergillus nidulans by the orotidine-5’-phosphate decarboxylase gene of Neurospora crassa. Biochem. Biophys. Res. Commun. 112:284–289.

Bergen, L. G., A. Upshall, and N. R. Morris. 1984. S-phase, G2, and nuclear division mutants of Aspergillus nidulans. J. Bacteriol. 159:114–119.

Byers, B. 1981. Cytology of the yeast life cycle. In The Molecular Biology of the Yeast Saccharomyces: Life Cycle and Inheritance. J. N. Strathern, E. W. Jones, and J. R. Broach, editors. Cold Spring Harbor Laboratory, Cold Spring Harbor, NY. 59–96.

Clutterbuck, A. J. 1974. Aspergillus nidulans. In Handbook of Genetics. Vol. 2. R. C. King, editor. Plenum Publishing Corp., New York. 447–510.

Cove, D. J. 1977. The Genetics of Aspergillus nidulans. In The Genetics and Physiology of Aspergillus nidulans. I. E. Smith and J. A. Pateman, editors. Academic Press, London. 81–96.

Crivellone, M. D., M. Wu, and A. Trzagoloff. 1988. Assembly of the mitochondrial membrane system: analysis of structural mutants of the yeast coenzyme QH2-cytochrome c reductase. J. Biol. Chem. 263:14323–14333.

Doonan, J. H., and N. R. Morris. 1989. The bimG gene of Aspergillus nidulans, required for completion of anaphase, encodes a homolog of mammalian phosphoprotein phosphatase 1. Cell. 57:987–996.

Doonan, J. H., G. I. Jenkins, D. J. Cove, and C. W. Lloyd. 1986. Microtubules connect the migrating nucleus to the prospective division site during side branch formation in the moss Physcomitrella patens. Eur. J. Cell Biol. 41:157–164.

Dutcher, S. K., and L. H. Hartwell. 1983. Genes that act before conjugation to prepare the Saccharomyces cerevisiae nucleus for caryogamy. Cell. 33:203–210.

Engle, D. B., J. H. Doonan, and N. R. Morris. 1988. Cell-cycle modulation of MPM-2 specific spindle pole body phosphorylation in Aspergillus nidulans. Cell Motil. Cytoskeleton. 10:434–437.

Gambino, J., L. G. Bergen, and N. R. Morris. 1984. Effects of mitotic and tubulin mutations on microtubule architecture in actively growing protoplasts of Aspergillus nidulans. J. Cell Biol. 99:830–838.

Gunning, B. E. S. 1982. The cytokinetic apparatus: its development and spatial regulation. In The Cytoskeleton in Plant Growth and Development. C. W. Lloyd, editor. Academic Press, London. 229–294.

Lloyd, C. W., K. J. Pearce, D. J. Rawlins, R. W. Ridge, and P. J. Shaw. 1987. Endoplasmic microtubules connect the advancing nucleus to the tip of legume root hairs, but F-actin is involved in basipetal migration. Cell Motil. Cytoskeleton. 8:27–36.

Lutz, D. A., and S. Inouye. 1982. Coleomycin but not cytochalasin inhibits asymmetric nuclear positioning prior to unequal cell division. Biol. Bull. (Woods Hole). 163:373–374.

Maniatis, T., E. F. Fritsch, and J. Sambrook. 1982. Molecular Cloning: A Laboratory Manual. Cold Spring Harbor Laboratory, Cold Spring Harbor, NY. 545 pp.

May, G. S., J. Gambino, J. A. Weatherbee, and N. R. Morris. 1985. Identification and functional analysis of beta-tubulin genes by site specific integrative transformation of Aspergillus nidulans. J. Cell Biol. 100:712–719.

Mayer, S. L. F., G. W. Kaminsky, and B. I. Heath. 1988. Nuclear migration in a nud mutant of Aspergillus nidulans is inhibited in the presence of a quantitatively normal population of cytoplasmic microtubules. J. Cell Biol. 106:773–778.

Melah, P. B., and M. D. Rose. 1990. KAR3, a kinesin-related gene required for yeast nuclear fusion. Cell. 60:1029–1041.

Miller, B. L., K. Y. Miller, and W. E. Timberlake. 1985. Direct and indirect gene replacement in Aspergillus nidulans. Mol. Cell. Biol. 5:1714–1721.

Morris, N. R. 1976. Mitotic mutants of Aspergillus nidulans. Genet. Res. 26:237–254.

Oakley, B. R., and N. R. Morris. 1980. Nuclear movement is beta-tubulin dependent in Aspergillus nidulans. Cell. 19:255–262.

Oakley, B. R., and N. R. Morris. 1981. A beta-tubulin mutation in Aspergillus nidulans that blocks microtubule function without blocking assembly. Cell. 24:837–845.

Oakley, B. R., and N. R. Morris. 1983. A mutation in Aspergillus nidulans that...
blocks the transition from interphase to prophase. *J. Cell Biol.* 96:1155–1158.

Oakley, B. R., and J. E. Rinehart. 1985. Mitochondria and nuclei move by different mechanisms in *Aspergillus nidulans*. *J. Cell Biol.* 101:2392–2397.

Osmani, S. A., G. S. May, and N. R. Morris. 1987. Regulation of the mRNA levels of nimA, a gene required for the G2-M transition in *Aspergillus nidulans*. *J. Cell Biol.* 104:1495–1504.

Osmani, S. A., D. B. Engle, J. H. Doonan, and N. R. Morris. 1988a. Spindle formation and chromosome condensation in cells blocked at interphase by mutation of a negative cell cycle control gene. *Cell.* 52:241–251.

Osmani, S. A., R. T. Pu, and N. R. Morris. 1988b. Mitotic induction and maintenance by overexpression of a G2-specific gene that encodes a potential protein kinase. *Cell.* 53:237–244.

Pontecorvo, G., J. A. Roper, C. M. Hemmons, K. D. MacDonald, and A. W. J. Butlin. 1953. The genetics of *Aspergillus nidulans*. *Adv. Genet.* 5:141–238.

Reeve, W. J., and F. P. Kelly. 1983. Nuclear position in the cells of the mouse early embryo. *J. Embryol. Exp. Morphol.* 75:117–139.

Rose, M. D., and G. R. Fink. 1987. KAR1, a gene required for function of both intranuclear and extranuclear microtubules in yeast. *Cell.* 48:1047–1060.

Sanger, F., S. Nicklen, and A. R. Coulson. 1977. DNA sequencing with chain-terminating inhibitor. *Proc. Natl. Acad. Sci. USA.* 74:5463–5467.

Schatten, G. 1982. Motility during fertilization. *Int. Rev. Cytol.* 79:59–163.

Schatten, G., H. Schatten, T. H. Bestor, and R. Balczon. 1982. Taxol inhibits the nuclear movements during fertilization and induces asters in unfertilized sea urchin eggs. *J. Cell Biol.* 94:455–465.

Schatten, G., H. Schatten, I. Spector, C. Cline, N. Pawelez, C. Simerly, and C. Petzelt. 1986. Latrunculin inhibits the microfilament-mediated processes during fertilization, cleavage and early development in sea urchins and mice. *Exp. Cell Res.* 166:191–208.

Schroeder, T. E. 1987. Fourth cleavage of sea urchin blastomers: microtubule patterns and myosin localization in equal and unequal cell divisions. *Dev. Biol.* 124:9–22.

Timberlake, W. E., and M. A. Marshall. 1988. Genetic regulation of development in *Aspergillus nidulans*. *Trends Genet.* 4:162–169.

Towbin, H., T. Spaehelin, and J. Gordon. 1979. Electrophoretic transfer from polyacrylamide gels to nitrocellulose sheets: procedures and some applications. *Proc. Natl. Acad. Sci.* USA. 76:4350–4354.

Wolf, R. 1978. The cytaster, a colchicine-sensitive migration organelle of cleavage nuclei in an insect egg. *Dev. Biol.* 62:464–472.

Zolaker, M., and I. Erk. 1976. Division and migration of nuclei during early embryogenesis of *Drosophila melanogaster*. *Journal of Microbiology of the Cell.* 25:97–106.