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[SHORT COMMUNICATION]

Oryzias curvinotus* Has *DMY*, a Gene That Is Required for Male Development in the Medaka, *O. latipes

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ABSTRACT—*DMY* is a Y-specific DM-domain gene required for male development and appears to be the sex-determining gene in the teleost fish medaka, *Oryzias latipes*. Although the genomic region containing *DMY* appears to have originated through duplication of the *DMRT1* region, it is unknown when the duplication occurred. Here we show that *O. curvinotus* also has the *DMY* gene on the Y chromosome, which is homologous to the Y chromosome of medaka, and that *DMY* is expressed in XY embryos. A phylogenetic tree based on the amino acid sequence including the DM-domain shows that *DMY* was derived from *DMRT1* immediately before speciation of *O. latipes* and *O. curvinotus*.

Key words: medaka, *DMY*, *DMRT1*, sex determination

INTRODUCTION

Although the sex-determining gene *Sry* on the Y chromosome has been identified as the testis-determining gene in mammals, no equivalent gene has been found in non-mammalian vertebrates. Recently, we found a Y-linked gene with properties consistent with that of a sex-determining gene in the medaka (*Oryzias latipes*). This gene, named *DMY* (DM-domain gene on the Y chromosome), encoded a protein that contains a DNA-binding motif called a DM-domain, which was originally described as a DNA-binding motif shared between *doublesex* (*dsx*) in *Drosophila melanogaster* and *mab-3* in *Caenorhabditis elegans* (Raymond *et al.*, 1998). DM-domain containing genes have also been found in many vertebrate species. One DM-domain containing gene, *DMRT1* (DM-related transcription factor 1) appears to be involved in a sex-determining cascade (Raymond *et al.*, 1999; Smith *et al.*, 1999; De Grandi *et al.*, 2000; Guan *et al.*, 2000; Kettlewell *et al.*, 2000; Marchand *et al.*, 2000; Moniot *et al.*, 2000).

In medaka, the nucleotide sequences of *DMY* and *DMRT1* have a similarity of 83% (based on cDNA sequences) and the genomic region containing *DMY* appears to have originated through duplication of the *DMRT1* region (Brun-

ner *et al.*, 2001; Nanda *et al.*, 2002). We report here phylogenetic relationships between *O. curvinotus* *DMY* and *DMRT1*, and discuss the time *DMY* acquired its sex-determining function.

MATERIALS AND METHODS**Linkage analysis**

O. curvinotus was maintained by mass mating at Niigata University.

For genotyping, genomic DNA was extracted from a part of the caudal fin as described previously (Matsuda *et al.*, 1997).

Genomic PCR was performed using the primers for *O. latipes* *DMRT1* and *DMY*: PG17.25, CCCACCAGATCCTATACAAGTGAC; PG17.48, GGCTGGTAGAAGTTGTAGTAGGAGGTTT. PCR conditions were 5 min 95°C, followed by 30 cycles of 20 s at 96°C, 30 s at 55°C, 60 s at 72°C, followed by 5 min at 72°C. The primers for *Casp6* were described previously (Kondo *et al.*, 2001).

Expression analysis

Genomic DNA and total RNA were extracted from each hatched embryo as described (Matsuda *et al.*, 2002). Genomic PCR was performed using primers for *DMRT1* and *DMY* as described above. RT-PCR was performed using a OneStep RT-PCR kit (Qiagen). PCR conditions were 30 min at 55°C; 15 min at 95°C; 20 s at 96°C, 30 s at 55°C, 60 s at 72°C for 30 cycles; and 5 min at 72°C. Approximately 100 ng of total RNA was used as template. For RT-PCR of *DMY*, the same primer set of genomic PCR was used. The PCR conditions and specific primers for *PG04* were described previously (Matsuda *et al.*, 2002). RT-PCR products were confirmed by direct sequencing.

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Phylogenetic analysis

A phylogenetic tree was constructed using MEGA2 software (Kumar *et al.*, 2001) in which distances were made to be proportional to the number of different amino acids. Human DMRT2 was used as an outgroup.

RESULTS AND DISCUSSION

Because the nucleotide sequence of *DMY* is similar to that of *DMRT1*, many PCR primers can be used on both genes. We found that a PCR primer pair designed for *DMY* and *DMRT1* of medaka could amplify *DMY* and *DMRT1* of *O. curvinotus* (Fig. 1). To determine whether *DMY* is on the Y chromosome of *O. curvinotus*, we first checked the *O. curvinotus* genome of our stock by using PCR of *DMY* and *Casp6*, respectively. *Casp6* is a DNA marker that has been reported to be sex-linked in *O. latipes* and *O. curvinotus* (Kondo *et al.*, 2001). In our stock, males have *DMY* and are heterogametic in *Casp6*, whereas females do not have *DMY*

and are homogametic in *Casp6*. We then mated males and females and obtained 57 offspring (30 males and 27 females). All the male progeny had the paternal genotype, whereas all the female progeny had the maternal genotype. This result indicates that *O. curvinotus* also has an XX-XY sex-determining system and that *DMY* is located on the Y chromosome, which is homologous to the medaka Y chromosome.

Furthermore, we obtained cDNA sequences of the coding region of *DMY* (from embryos) and *DMRT1* (from testis) by the RACE method. A cDNA sequence of *DMY* was found to encode a putative protein of 280 amino acids, whereas a cDNA sequence of *DMRT1* was found to encode a putative protein of 276 amino acids (Fig. 2). A phylogenetic tree based on the amino acid sequences of the DM-domains of these and other *DMY* and *DMRT1* in the database indicated (Fig. 3) that *Oryzias* *DMY* made a clade with *Oryzias* *DMRT1*. The monophyly of *Oryzias* *DMY/DMRT1* was sup-

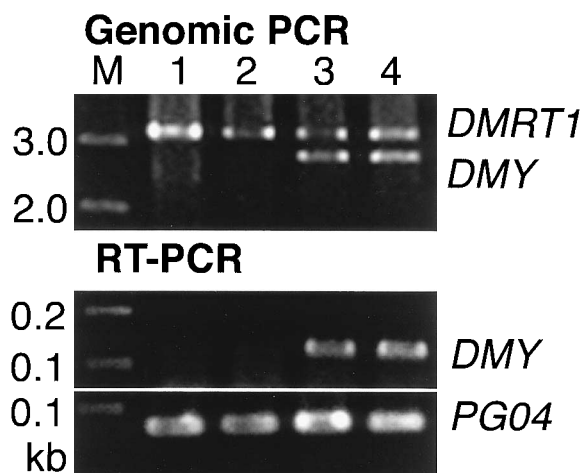


Fig. 1. Genomic and RT-PCR analyses of *DMRT1* and *DMY* of embryos just after hatching. Some of results are shown. Lanes 1–4 show each embryo. Genomic PCR products were electrophoresed in a 1% agarose gel with a 1-kb DNA ladder, whereas RT-PCR products were electrophoresed in a 2% agarose gel with a 100-bp DNA ladder.



Fig. 2. Alignment of *DMY* and *DMRT1* proteins in *O. latipes* (Ola) and *O. curvinotus* (Ocu). Period indicates sequence identity; dash indicates a gap; asterisk indicates a stop codon. The DM-domain occurs at positions 23–76. A single base pair deletion at position 272 of Ola *DMY* has caused a frame-shift mutation. The DNA Data Bank of Japan (DDBJ) accession numbers of the *O. curvinotus* *DMY* and *DMRT1* cDNA sequences are AB091695 and AB091696.

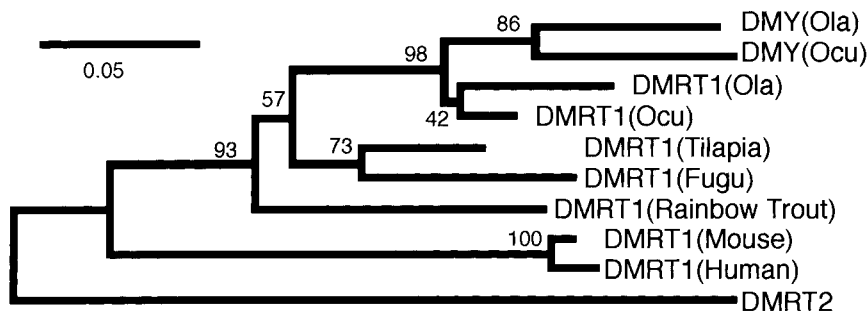


Fig. 3. A neighbor-joining tree based on the amino acid sequences from positions 21 to 109 in Fig. 2. The GenBank accession numbers of the sequences used in the tree were as follows: AF203489 (tilapia *DMRT1*), AJ295039 (fugu *DMRT1*), AF209095 (rainbow trout *DMRT1*), AF202778 (mouse *DMRT1*), AF130728 (human *DMRT1*) and AF284223 (human *DMRT2*). The scores above each branch represent bootstrap values of 1000 times.

ported by a 98% bootstrap value. The clade was divided into two lineages; one consisted of the DMYs of *O. latipes* and *O. curvinotus*, and the other consisted of the DMRT1s of these two species. The bootstrap value of the former clade was high (86%), while that of the latter clade was low (42%). These results suggested that DMY was derived from DMRT1 immediately before speciation of *O. latipes* and *O. curvinotus*.

Oryzias curvinotus has the same sex-determining mechanism as medaka and has DMY on the Y chromosome, which suggests that DMY also has a role in sex determination of *O. curvinotus*. The branch length of DMY is longer than that of DMRT1 in the phylogenetic tree (Fig. 3). This means that DMY has more mutations than DMRT1 and suggests that DMY accumulated these mutations after it acquired its sex-determining function. In other words, the rate of evolution of DMY, which is a Y-linked sex-determining gene, is higher than that of DMRT1, which is the origin of the Y-linked sex-determining gene. The rate of evolution of Sry, which is the sex-determining gene on the Y chromosome of mammals, is also higher than that of Sox family genes (Bowles *et al.*, 2000). These results suggest that a new sex-determining gene generated by a gene duplication event in the sex chromosome tends to evolve fast.

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