

## Functional Analysis of Mouse Kinesin Motor Kif3C

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**Members of the kinesin II family are thought to play essential roles in many types of intracellular transport. One distinguishing feature of kinesin II is that it generally contains two different motor subunits from the Kif3 family. Three Kif3 family members (Kif3A, Kif3B, and Kif3C) have been identified and characterized in mice. Intracellular localization and biochemical studies previously suggested that Kif3C is an anterograde motor involved in anterograde axonal transport. To understand the in vivo function of the Kif3C gene, we used homologous recombination in embryonic stem cells to construct two different knockout mouse strains for the Kif3C gene. Both homozygous Kif3C mutants are viable, reproduce normally, and apparently develop normally. These results suggest that Kif3C is dispensable for normal neural development and behavior in the mouse.**

All cells require protein synthesis followed by transport and correct targeting of these proteins to their proper destinations. Biochemical, genetic, and intracellular localization studies of kinesin motors have suggested that some of these motor proteins may power intracellular transport events in neurons (1, 6, 7). As microtubule-dependent motors, members of the kinesin superfamily share extensive sequence similarity within the motor domain but display diversification in their tail domains. The motor domain is composed of a catalytic domain that hydrolyzes ATP and interacts with the microtubule track and a short neck domain important for processive movement and control of direction. The tail domains have been suggested to provide different cargo-binding or regulatory partners and to confer the ability to form different types of oligomers (21).

The kinesin II holoenzyme was first identified in sea urchins and subsequently identified in most species and found to be composed of two different motor subunits from the Kif3 family (3). Genetic and localization experiments in *Chlamydomonas*, *Tetrahymena thermophila* (4, 22), *Caenorhabditis elegans* (19), sea urchins (5), and mice (9, 23, 24) suggest that kinesin II in many cases is essential for the construction and maintenance of motile and nonmotile cilia and flagella (11, 18). In *Chlamydomonas*, kinesin II appears to transport a large protein complex, termed a raft, possibly with protein cargoes attached, from the sites of synthesis in the cell body to the sites of utilization at the tip of the flagellum (4, 10, 16).

Three members (Kif3A, Kif3B, and Kif3C) of the Kif3 family have been characterized in mice (9, 23, 24). Kif3A was previously reported to form a heterodimer with Kif3B or Kif3C, but Kif3B and Kif3C cannot associate with each other (14, 24). Mouse mutants lacking either the Kif3A or Kif3B gene resulted in embryonic lethality and embryonic ciliary morphogenesis defects (13, 15, 20), suggesting that they also play roles in ciliary morphogenesis in mammals. When Kif3A was specifically deleted from retinal photoreceptors using the

Cre-loxP system, complete loss of Kif3A caused large accumulations of opsin, arrestin, and membranes within the photoreceptor inner segment, which suggests that kinesin II is required to transport opsin and arrestin from the inner to the outer segments (12). In contrast to Kif3A and Kif3B, whose expression is ubiquitous, Kif3C expression is highly enriched in both the central and peripheral nervous systems. Intracellular localization and biochemical studies suggest that Kif3C is an anterograde motor which may be involved in anterograde axonal transport (14, 24). Nevertheless, the precise in vivo functions of Kif3C remain unknown.

To understand the in vivo function of the Kif3C gene, we used homologous recombination in embryonic stem cells to construct two types (Kif3C<sup>typeI</sup> and Kif3C<sup>null</sup>) of knockout mouse strain for the Kif3C gene. In the Kif3C<sup>typeI</sup> mice, the motor region and half of the  $\alpha$ -helical coiled-coil domain of the Kif3C protein were removed, but the rest of the  $\alpha$ -helical coiled-coil domain and the tail of the protein still remained. In the Kif3C<sup>null</sup> mice, no Kif3C mRNA or protein can be detected by Northern and Western blotting, which suggests that homozygous Kif3C<sup>null</sup> mice are null mutants. Both homozygous Kif3C<sup>typeI</sup> and Kif3C<sup>null</sup> mutants are viable, reproduce normally, and apparently develop normally. These results suggest that Kif3C is dispensable for normal neural development and behavior in the mouse.

### MATERIALS AND METHODS

**Cloning and mapping of the Kif3C gene.** A 1.5-kb Kif3C cDNA fragment encoding the motor domain of the Kif3C protein was used for isolating Kif3C genomic clones from a mouse 129/SVJ genomic phage library (a gift from the lab of Jamey Marth). The genomic clones we isolated from the library were then cloned into the vector Bluescript (Stratagene, La Jolla, Calif.). The map of the Kif3C gene was obtained by digestion of the genomic clones using different restriction enzymes and probing with different regions of the Kif3C cDNA. Southern blotting and other molecular biological techniques were performed according to standard methods.

**Generation of targeting vectors and ES cells.** We made two targeting vectors. One vector was built using plox (a gift from the lab of Jamey Marth) (2). In this vector we deleted a 2.1-kb DNA fragment between *Bam*HI and *Eco*RV of the Kif3C gene (Fig. 1A). The DNA fragment contains the first exon (2.0 kb) and part of the first intron (0.1 kb) of the Kif3C gene and encodes amino acid residues 1 to 518 of the Kif3C protein. The linearized targeting construct with *Nde*I was introduced into R1 embryonic stem (ES) cells via electroporation (8) prior to selection with 250  $\mu$ g of active G418/ml for 7 to 9 days. ES clones

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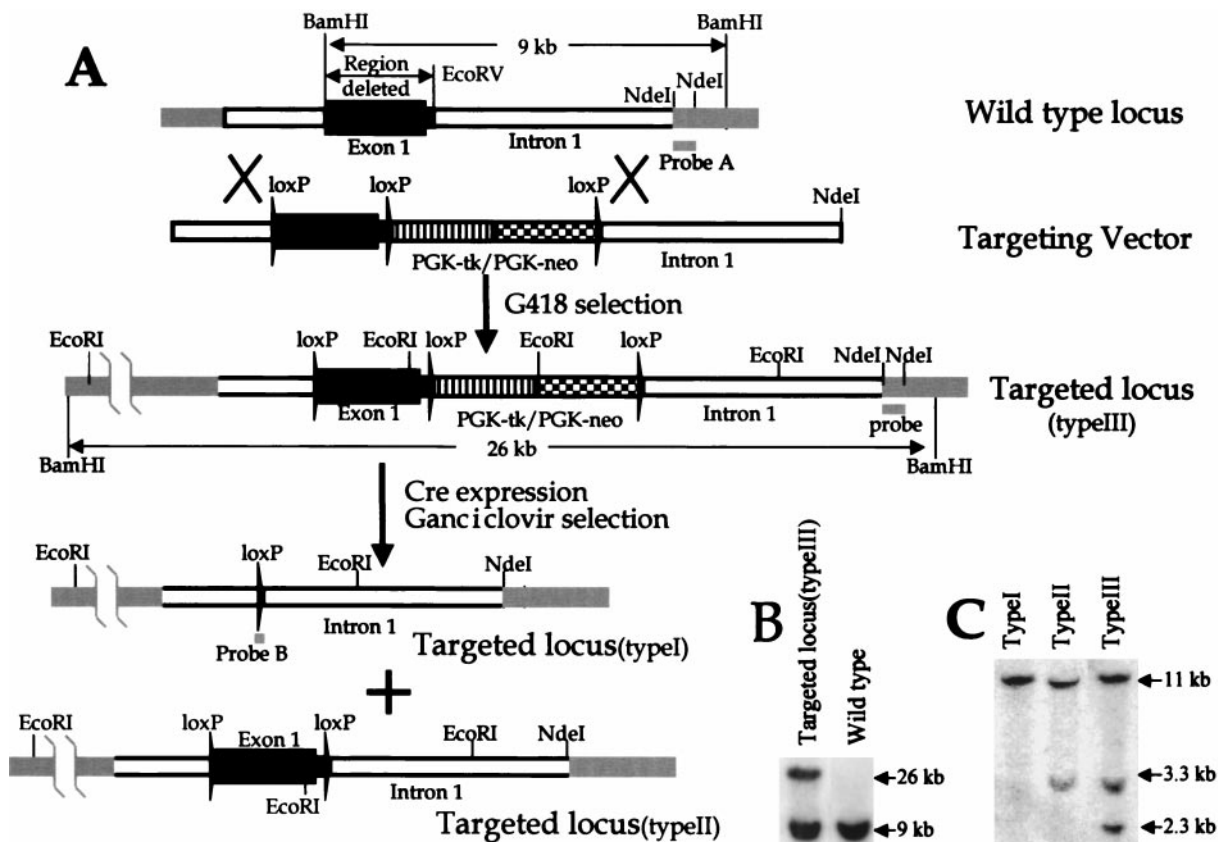


FIG. 1. Generation and analysis of *Kif3C*<sup>type I</sup> and *Kif3C*<sup>type II</sup> mutants in ES cells. (A) Strategy for generating *Kif3C*<sup>type I</sup> and *Kif3C*<sup>type II</sup> mutants. A 2.1-kb DNA fragment between *Bam*HI and *Eco*RV of the *Kif3C* gene was flanked with two loxP fragments. A PGK-neo and PGK-tk selection marker with a third loxP fragment was added into the vector. (B) Southern analysis of targeted ES cells (*Kif3C*<sup>type III</sup>). ES cell genomic DNA was cut with *Bam*HI and probed with a 600-bp *Nde*I DNA fragment (probe A). The wild-type and targeted *Kif3C*<sup>type III</sup> alleles were detected as 9- and 26-kb bands, respectively. (C) Southern analysis of Cre-transfected ES cells. *Kif3C*<sup>type III</sup> (+/−) ES cells were transfected with the Cre plasmid to excise the DNA fragment flanked by loxP sites. ES clones resistant to ganciclovir were analyzed by Southern analysis, in which the genomic DNA was digested with *Eco*RI and probed with a loxP fragment (probe B). Each band represents a loxP fragment. Two types (*Kif3C*<sup>type I</sup> and *Kif3C*<sup>type II</sup>) of ES cells were obtained.

resistant to G418 were analyzed by Southern analysis. When the ES cell genomic DNA was digested with *Bam*HI and probed with a 600-bp DNA fragment between two *Nde*I cut sites (Fig. 1A), the wild-type and targeted *Kif3C* alleles (type III) were detected as 9- and 26-kb bands, respectively (Fig. 1B). The targeted *Kif3C* allele was confirmed by Southern blotting with different restriction enzymes and probes. ES cell clones bearing a targeted *Kif3C* allele (type III) were electroporated with Cre expression plasmid pCre-Hygro (a gift from the lab of Jamey Marth) to excise the DNA fragment flanked by loxP sites (2). ES clones resistant to ganciclovir (2  $\mu$ M) were analyzed by Southern analysis in which the genomic DNA was digested with *Eco*RI and probed with a loxP fragment (a gift from the lab of Jamey Marth). Two types of ES cells were obtained (Fig. 1A and C). One, bearing only one copy of the loxP sequence, is called *Kif3C*<sup>type I</sup>, in which the 2.1-kb *Kif3C* DNA fragment was deleted. The other, containing two copies of the loxP sequence, is called *Kif3C*<sup>type II</sup>, in which the *Kif3C* gene should function normally because the two loxP fragments were inserted in an intron and the 5' nontranslated region and did not alter other aspects of the *Kif3C* gene.

Using a traditional strategy, we also made a second targeting vector to delete a 4.5-kb DNA fragment between *Bam*HI and *Xho*I of the *Kif3C* gene (see Fig. 3A). This DNA fragment contains the first exon (2.0 kb) and part of the first intron (2.5 kb) of the *Kif3C* gene and also encodes amino acid residues 1 to 518 of the *Kif3C* protein. In the targeting vector, the deleted region was replaced with a 1.7-kb phosphoglycerine kinase promoter (PGK)-driven *neo* cassette which contains a poly(A) signal and should mediate termination of transcription next to the deleted region. To increase the frequency of homologous recombination in ES cells, the targeting vector also included a negative selection marker, PGK-tk (see Fig. 3A). The vector was linearized with *Xho*I (see Fig. 3A) and

introduced into R1 ES cells by electroporation as was done for the first targeting vector (8). ES clones resistant to both G418 and ganciclovir were analyzed by Southern analysis. The wild-type and targeted *Kif3C* alleles (*Kif3C*<sup>null</sup>) were detected as 10- and 7.5-kb bands (see Fig. 3B), respectively, by digesting the ES cell genomic DNA with *Xba*I and probing with a 1.5-kb *Bam*HI and *Eco*RI DNA fragment (see Fig. 3A). The targeted *Kif3C* allele was confirmed by Southern blotting with different restriction enzymes and probes.

**Generation of *Kif3C* targeted mice.** Three types (*Kif3C*<sup>type I</sup>, *Kif3C*<sup>type II</sup>, and *Kif3C*<sup>null</sup>) of ES cells were used for generating chimeric mice (129/SvJ-derived ES cells in blastocysts of C57BL/6J mice) as previously described (8). When the chimeras were backcrossed to C57BL/6J mice, heterozygous *Kif3C*<sup>type I</sup> (+/−), *Kif3C*<sup>type II</sup> (+/−), and *Kif3C*<sup>null</sup> (+/−) mice were obtained. These heterozygous mice were used for interbreeding to produce homozygous *Kif3C*<sup>type I</sup> (−/−), *Kif3C*<sup>type II</sup> (−/−), and *Kif3C*<sup>null</sup> (−/−) mice, respectively. The genotypes of animals were obtained by Southern blotting or PCR as indicated.

**Analysis of *Kif3C* targeted mice.** Gross and histopathological analyses employed standard techniques. Littermate *Kif3C* (+/+) and either *Kif3C*<sup>type I</sup> (−/−) or *Kif3C*<sup>null</sup> (−/−) mice were examined for appearance, posture, circadian activity, home cage assessment, rotating rod task performance, and balance. These behavioral tests were carried out using standard protocols.

**Western analysis and immunoprecipitation.** Monoclonal anti-*Kif3A* and polyclonal anti-*Kif3B* antibodies were from Babco. Monoclonal anti-actin antibody was from Boehringer Mannheim. Monoclonal antibody SUK4 is directed against the kinesin heavy chain. Affinity-purified rabbit antibodies against the C terminus of mouse *Kif3C* were prepared and Western analysis and immunoprecipitation of mouse brain lysates were performed as described previously (24).

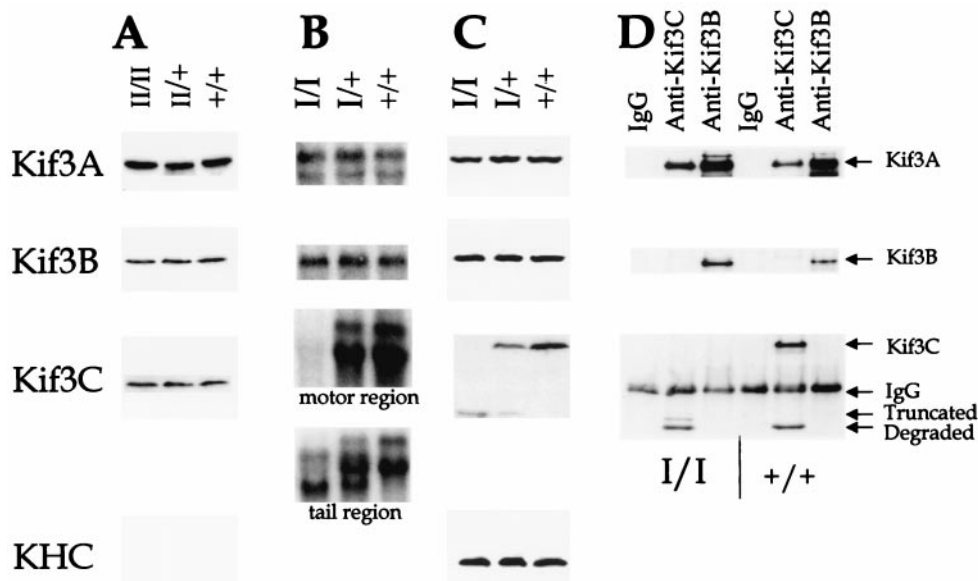


FIG. 2. Analysis of Kif3C<sup>typeI</sup> and Kif3C<sup>typeII</sup> mice. (A) Western analysis of Kif3C<sup>typeII</sup> mice. Brain lysates from Kif3C<sup>typeII</sup> (-/-), Kif3C<sup>typeII</sup> (+/-), and wild-type (+/+) littermates were analyzed by sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE). The duplicate blots were probed with antibodies against Kif3A, Kif3B, and Kif3C. (B) Northern analysis of Kif3C<sup>typeI</sup> mice. Total RNA was isolated from the Kif3C<sup>typeI</sup> mouse brains and analyzed in a formaldehyde-agarose gel. The duplicate blots were probed with cDNA of Kif3A, Kif3B, and Kif3C. Two different probes, encoding either the motor region or the tail region as indicated, were used for Kif3C. (C) Western analysis of Kif3C<sup>typeI</sup> mice. Brain lysates from Kif3C<sup>typeI</sup> mice were analyzed by SDS-PAGE. The duplicate blots were probed with antibodies against Kif3A, Kif3B, and Kif3C and a monoclonal antibody, SUK4, for kinesin heavy chain. The antibodies against Kif3C detected a truncated Kif3C protein. (D) Immunoprecipitation-Western analysis of Kif3C<sup>typeI</sup> mice. Brain lysates from Kif3C<sup>typeI</sup> mice were immunoprecipitated with anti-Kif3C or anti-Kif3B antibodies or immunoglobulin G (IgG) as a control. The immunoprecipitated samples were analyzed by SDS-PAGE. The same blot was probed and re-probed with antibodies against Kif3A, Kif3B, and Kif3C. The samples in the left three lanes were from Kif3C<sup>typeI</sup> (-/-) mice and the samples in the right three lanes were from wild-type littermates. (The truncated Kif3C protein in wild-type mice was probably generated from protein degradation.)

## RESULTS AND DISCUSSION

### Generation and analysis of Kif3C<sup>typeI</sup> and Kif3C<sup>typeII</sup> mice.

To explore the in vivo function of the Kif3C gene, we first made a targeting vector to delete a 2.1-kb DNA fragment of the Kif3C gene in ES cells. Because we were concerned that Kif3C<sup>typeI</sup> (-/-) mice might be inviable, Kif3C<sup>typeII</sup> (-/-) mice, which are conditional (tissue specific) knockout mice, would serve for functional analysis of the Kif3C gene. As described in Materials and Methods, we obtained both Kif3C<sup>typeI</sup> (+/-) and Kif3C<sup>typeII</sup> (+/-) ES cells (Fig. 1A). When both Kif3C<sup>typeI</sup> (+/-) and Kif3C<sup>typeII</sup> (+/-) ES cells were injected into the blastocysts of C57BL/6J mice, several chimeras were generated. These chimeras were successfully used to generate homozygous Kif3C<sup>typeI</sup> (-/-) and Kif3C<sup>typeII</sup> (-/-) mice, respectively. Both homozygous Kif3C<sup>typeI</sup> (-/-) and Kif3C<sup>typeII</sup> (-/-) mice were normal and healthy, just like their wild-type littermates. The ratios of wild-type Kif3C (+/+), heterozygous Kif3C<sup>typeI</sup> (+/-) or Kif3C<sup>typeII</sup> (+/-), and homozygous Kif3C<sup>typeI</sup> (-/-) or Kif3C<sup>typeII</sup> (-/-) mice from the heterozygous parents yielded the predicted Mendelian ratios of 1:2:1 expected for nonlethal alleles. Thus, the Kif3C<sup>typeI</sup> (-/-) and Kif3C<sup>typeII</sup> (-/-) pups were no less viable than their wild-type and heterozygous littermates.

For the Kif3C<sup>typeII</sup> (-/-) mice, it is expected that the two loxP fragments were inserted into an intron and nontranslated region without altering other aspects of the Kif3C gene, and thus this Kif3C allele should function normally. In fact, when

Western blotting was used to analyze brain lysates from Kif3C<sup>typeII</sup> mice, the amount of the Kif3C protein in the Kif3C<sup>typeII</sup> (-/-) mice was normal compared to that of their heterozygous Kif3C<sup>typeII</sup> (+/-) and wild-type littermates (Fig. 2A). As controls, the Kif3A and Kif3B protein levels also did not change.

In Kif3C<sup>typeI</sup> mice, we deleted a 2.1-kb DNA fragment of the Kif3C gene (Fig. 1A). The 2.1-kb DNA fragment encodes amino acid residues 1 to 518 of the Kif3C protein, which has a total of 796 amino acids (24). This deletion includes the whole motor region and half of the  $\alpha$ -helical coiled-coil domains of the motor domain. Since the deleted motor domain contains functional ATP binding and ATPase activity sites, it is likely that the deletion will completely abolish the function of Kif3C. However, due to the design used, we did not put a transcriptional stop signal immediately after the deleted region. As a result of this, although the 2.1-kb DNA fragment was successfully deleted and no transcript containing the motor region was detected by Northern blotting, a small transcript encoding the tail region of Kif3C was detectable in the Kif3C<sup>typeI</sup> (-/-) mice (Fig. 2B). Due to the presence of an internal ATG code in this transcript, a truncated Kif3C protein could be made in the Kif3C<sup>typeI</sup> (-/-) mice. This fragment was indeed detected by Western blotting using antibodies against the tail region of the Kif3C proteins (Fig. 2C). The mRNA and protein levels of both the Kif3A and Kif3B genes apparently do not change in the Kif3C<sup>typeI</sup> mice (Fig. 2B and C).

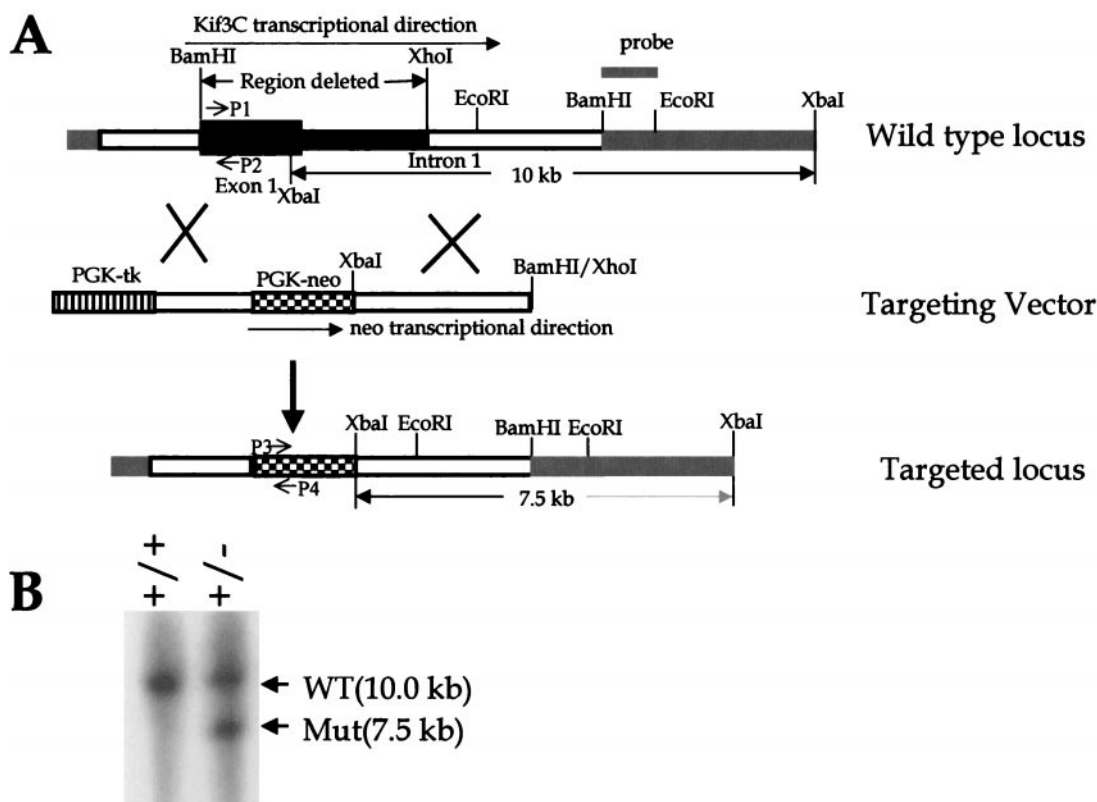


FIG. 3. Generation and analysis of  $Kif3C^{null}$  mutants in ES cells. (A) Strategy for generating  $Kif3C^{null}$  mutants. One 4.5-kb DNA fragment between *Bam*HI and *Xho*I of the *Kif3C* gene was replaced with a 1.7-kb PGK-neo cassette. The targeting vector included a negative selection marker, PGK-tk. The targeting vector was linearized with *Xho*I and introduced into R1 ES cells. (B) Southern analysis of ES cells. ES cell genomic DNA was cut with *Xba*I and probed with a 1.5-kb *Bam*HI/*Eco*RI DNA fragment. The wild-type (WT) and targeted *Kif3C* (Mut) alleles were detected as 10.0- and 7.5-kb bands, respectively. P1, P2, P3, and P4 indicate the locations of primers used for genotyping  $Kif3C^{null}$  mice (Fig. 4).

To examine whether the truncated *Kif3C* protein could associate with *Kif3A*, antibodies against *Kif3B* and *Kif3C* were used for immunoprecipitation of brain lysates from the  $Kif3C^{type1}$  mice. The immunoprecipitated samples were analyzed by Western blotting by using antibodies against *Kif3A*, *Kif3B*, and *Kif3C*. We observed that immunoprecipitation from wild-type mice brings down not only full-length *Kif3C*, but also a small fragment of *Kif3C*; this fragment is only seen in immunoprecipitation experiments and not in Western blots (compare Fig. 2D to Fig. 2C and 4B). We think that the most likely explanation is that proteins are handled longer in the immunoprecipitation experiments and hence are more susceptible to degradation than in Western blot experiments. In support of this notion, there are two smaller bands detected in  $Kif3C^{type1}$  homozygous mutants (Fig. 2D) in the immunoprecipitation experiments, and one, the upper band in Western blots (Fig. 2C), is not seen in wild-type mice. Thus, the most plausible hypothesis is that the upper band is the truncated fragment of *Kif3C* generated from the internal start and the lower band is derived from the upper band by degradation as in wild-type mice. Nonetheless, as shown in Fig. 2D, like the full-length *Kif3C* protein (14, 24), the truncated *Kif3C* protein also specifically associates with *Kif3A* but not *Kif3B*. It was suggested previously that opposing charge interactions within the stalk domains of the *Kif3* family are important for generating heterodimers (17). This region, however, is deleted in the

$Kif3C^{type1}$  ( $-/-$ ) mice. The results in Fig. 2D demonstrate that the truncated *Kif3C* protein without the charged region still associates with *Kif3A*, suggesting that other interactions in addition to interactions within the stalk domains may play more important roles in selective associations among the subunits of the *Kif3* family.

There are two hypotheses to explain the normality of the  $Kif3C^{type1}$  ( $-/-$ ) mice. One is that *Kif3C* may not have an essential or major function and the other is that the truncated *Kif3C* protein associated with *Kif3A* may have some residual function. The second hypothesis was supported by a ligation experiment on sciatic nerves in the  $Kif3C^{type1}$  ( $-/-$ ) mice. The ligation experiments showed that the truncated *Kif3C* protein can be anterogradely transported into axons (data not shown). To further test these hypotheses, we made another knockout strain,  $Kif3C^{null}$  ( $-/-$ ).

**Generation and analysis of  $Kif3C^{null}$  mice.** Using standard methods, we used  $Kif3C^{null}$  ( $+/-$ ) ES cells (Fig. 3A) to generate  $Kif3C^{null}$  ( $-/-$ ) and wild-type littermates. In the  $Kif3C^{null}$  ( $-/-$ ) mice, a 4.5-kb DNA fragment of the *Kif3C* gene was deleted and replaced by a drug resistance cassette and a poly (A) signal. The 4.5-kb DNA fragment encodes amino acid residues 1 to 518 of the *Kif3C* protein. This deletion includes the whole motor region and half of the  $\alpha$ -helical coiled-coil domains of the motor domain similar to the  $Kif3C^{type1}$  ( $-/-$ ) mice. The deletion was confirmed by PCR

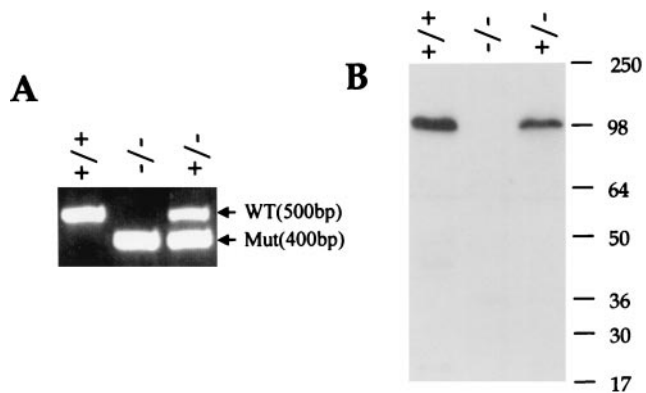


FIG. 4. Analysis of *Kif3C*<sup>null</sup> knockout mice. (A) PCR analysis of the *Kif3C*<sup>null</sup> knockout mice. A set of four primers was used for genotyping the *Kif3C*<sup>null</sup> mice. Two primers based on *Kif3C* sequences (forward P1, GGT CAT GAG CAG ATT CTG AC; reverse P2, GAG AGC TGA CCT CAT TCA TG) were used for PCR to amplify a 500-bp DNA fragment which is absent from the *Kif3C*<sup>null</sup> ( $-/-$ ) mutant locus. Another two primers based on the *neo* sequence (forward P3, GAT GGA TTG CAC GCA GGT TCT; reverse P4, AGG TAG CCG GAT CAA GCG TAT) were used for amplifying a 400-bp DNA fragment which is missing in the wild-type *Kif3C* locus. The positions of PCR primers are indicated in Fig. 3A. (B) Western analysis of *Kif3C*<sup>null</sup> knockout mice. Brain lysates from the *Kif3C*<sup>null</sup> mice were analyzed by SDS-PAGE. The blot was probed with antibodies against *Kif3C*, which was made using the C terminus of the *Kif3C* protein. No truncated *Kif3C* protein was detected. WT, wild type; Mut, targeted *Kif3C* alleles. Numbers to the right of panel B indicate molecular mass, in kiloDaltons.

(Fig. 4A) and by Western blotting (Fig. 4B). In genomic PCR of the *Kif3C* mice, a 500-bp DNA fragment which represents the *Kif3C* wild-type allele was found for both the wild-type (+/+) and heterozygous (+/-) mice but not for the homozygous mutant *Kif3C*<sup>null</sup> ( $-/-$ ) mice (Fig. 4A). In contrast, a 400-bp DNA fragment amplified from PGK-*neo* which represents the *Kif3C* mutated allele was found for both the heterozygous *Kif3C*<sup>null</sup> (+/-) and homozygous *Kif3C*<sup>null</sup> ( $-/-$ ) mutants but not for the wild type (+/+) mice (Fig. 4A). The results from PCR analysis were confirmed by Southern analysis using the same enzyme and probe as described for Fig. 3B

(data not shown). In Western analysis of the brain lysates from the *Kif3C*<sup>null</sup> ( $-/-$ ) mice and wild-type littermates, no *Kif3C*-specific protein was detected in the homozygous mutants using antibodies against the C terminus of the *Kif3C* protein. These results clearly indicate that the mice we generated are truly null for the *Kif3C* gene.

The ratios of wild-type (+/+), heterozygous (*Kif3C*<sup>null</sup> [+/-]), and homozygous (*Kif3C*<sup>null</sup> [ $-/-$ ]) mice from the heterozygous parents yielded the predicted Mendelian ratios of 1:2:1 expected for nonlethal alleles. Thus, the *Kif3C*<sup>null</sup> ( $-/-$ ) pups were no less viable than their wild-type and heterozygous littermates. Mice that were heterozygous (*Kif3C*<sup>null</sup> [+/-]) or homozygous (*Kif3C*<sup>null</sup> [ $-/-$ ]) for the *Kif3C* deletion appeared healthy (up to 1.5 years old), developed normally, and did not display any impairment of reproductive capacity and neonatal survival. The breeding pairs with either heterozygous  $\times$  heterozygous or homozygous  $\times$  homozygous animals produced litters similar in size to those produced by wild-type breeding pairs, demonstrating that the absence of the *Kif3C* protein does not hinder the fertility of male or female mice.

Since *Kif3C* is specifically expressed in the nervous system, we examined whether the deletion of the *Kif3C* gene affects mouse behaviors using a variety of tests. Mice were tested in a rotarod apparatus to assess their motor coordination, balance, and ataxia. No differences between the knockout mice (*Kif3C*<sup>null</sup> [ $-/-$ ]) and their wild-type littermates were observed.

At a gross phenotypic level, the absence of *Kif3C* had no discernible impact. *Kif3C*<sup>null</sup> ( $-/-$ ) mice were indistinguishable from their wild-type littermates with respect to body weight and body length. In addition, they exhibited no macroscopic or microscopic alterations in all organs examined (retina, brain, spinal cord, and sciatic nerve). Figure 5 shows the morphology of brain from wild type (Fig. 5A) and *Kif3C*<sup>null</sup> ( $-/-$ ) knockout (Fig. 5B) mice. No differences in the morphology of the brain between the *Kif3C* knockout mice and their littermates were observed. We found no differences in white or red blood cell counts or in levels of hemoglobin between wild-type and *Kif3C*<sup>null</sup> ( $-/-$ ) knockout mice, nor were alterations in embryonic development observed. These

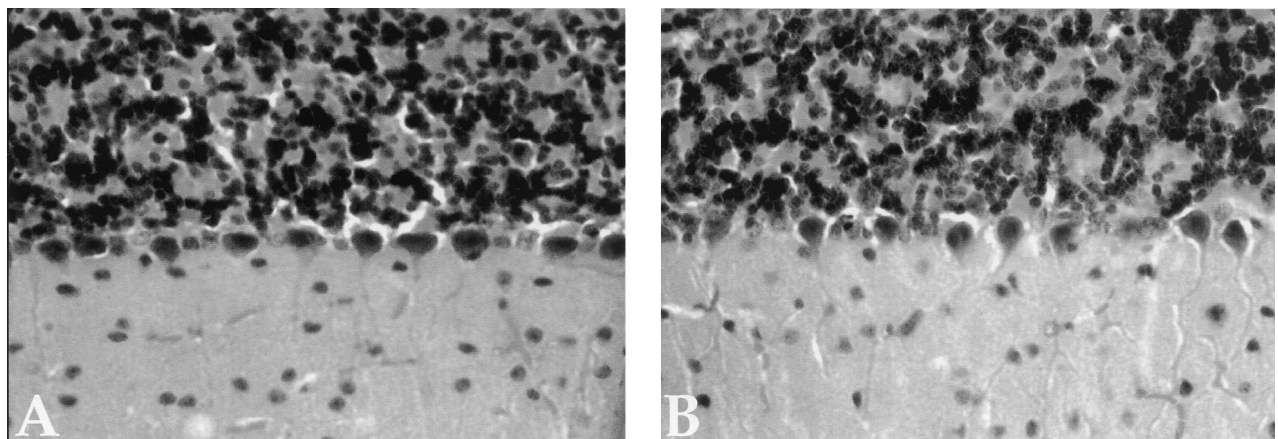


FIG. 5. Morphology of brain from wild-type (A) and *Kif3C*<sup>null</sup> ( $-/-$ ) (B) mice. Brains were isolated from adult animals perfused with paraformaldehyde, postfixed, and embedded in paraffin. Sections were stained with cresyl violet.

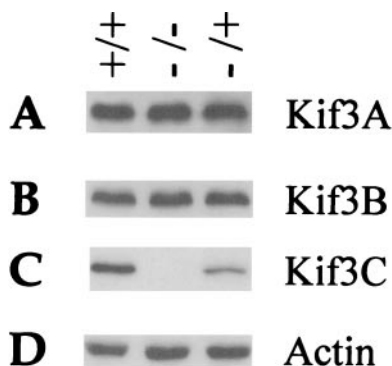


FIG. 6. Western analysis of Kif3C<sup>null</sup> (−/−) mice. Brain lysates from Kif3C<sup>null</sup> mice were analyzed by SDS-PAGE. The duplicate blots were probed with antibodies against Kif3A (A), Kif3B (B), Kif3C (C), and actin (D).

results suggest that Kif3C is dispensable for normal development and for many behaviors.

**Functions of Kif3C motor.** The neural-specific expression of Kif3C had suggested that Kif3C would play an important role in the nervous system. However, when we disrupted the Kif3C gene in mice, the nervous system apparently functioned normally in the homozygous mutants. This conclusion is supported by behavioral tests and histological analyses in which we found no difference between the Kif3C knockout mice and their wild-type littermates.

As a member of the Kif3 kinesin family, the loss of function of Kif3C in the mutants might be provided by another member of this family, such as Kif3A and Kif3B. However, when Kif3C<sup>null</sup> (−/−) mice were analyzed by Western blotting using anti-Kif3A and anti-Kif3B antibodies, like for actin the amount of Kif3A and Kif3B apparently did not change dramatically (Fig. 6).

Because of the difference between Kif3C and Kif3B expression patterns, slightly different microtubule-binding characteristics, and selective association with Kif3A as previously reported (14, 23, 24), Kif3B and Kif3C functions could be carried out in distinct tissues and cell types, or they could selectively power different types of cargoes. Since Kif3C and Kif3B are similar in sequence and association with Kif3A, it was also suggested that the Kif3A-Kif3C and Kif3A-Kif3B heterodimers may play similar roles in anterograde transport (24). Kif3A-Kif3C may have transport activities only in neural tissues, while Kif3A-Kif3B may have a more general role in transport in neural and other tissues. Thus, it is possible that the two motors each participate in the movement of overlapping types of cargoes, in which case they might be redundant in neural tissues. The mice we report in this paper may facilitate exploration of this issue.

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L.S.B.G. is an Investigator of the Howard Hughes Medical Institute.

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