

## Developmental Biology

Volume 243, Issue 2, 15 March 2002, Pages 312-325

Regular Article

### Direct Flight Muscles in *Drosophila* Develop from Cells with Characteristics of Founders and Depend on *DWnt-2* for Their Correct Patterning

Karen M. Kozopas<sup>a, b, 1</sup> ... Roel Nusse<sup>b</sup>

 **Show more**

<https://doi.org/10.1006/dbio.2002.0572>

[Get rights and content](#)

Under an Elsevier [user license](#)

[open archive](#)

#### Abstract

The direct flight muscles (DFMs) of *Drosophila* allow for the fine control of wing position necessary for flight. In *DWnt-2* mutant flies, certain DFMs are either missing or fail to attach to the correct epithelial sites. Using a temperature-sensitive allele, we show that *DWnt-2* activity is required only during pupation for correct DFM patterning. *DWnt-2* is expressed in the epithelium of the wing hinge primordium during pupation. This expression is in the vicinity of the developing DFMs, as revealed by expression of the muscle founder cell-specific gene *dumbfounded* in DFM precursors. The observation that a gene necessary for embryonic founder cell function is expressed in the DFM precursors suggests that these cells may have a similar founder cell role. Although the expression pattern of *DWnt-2* suggests that it could influence epithelial cells to differentiate into attachment sites for muscle, the expression of *stripe*, a transcription factor necessary for epithelial cells to adopt an attachment cell fate, is unaltered in the mutant. Ectopic expression of *DWnt-2* in the wing hinge during pupation can also create defects in muscle patterning without alterations in *stripe* expression. We conclude that *DWnt-2* promotes the correct patterning of DFMs through a mechanism that is independent of the attachment site differentiation initiated by *stripe*.

#### Keywords

muscle development; Wnt signaling; epithelial attachments; direct flight muscles





[Recommended articles](#)   [Citing articles \(26\)](#)

#### References






##### REFERENCES

- 1 N. Azpiazu, P.A. Lawrence, J.P. Vincent, M. Frasch  
**Segmentation and specification of the *Drosophila* mesoderm**  
*Genes Dev.*, 10 (1996), pp. 3183-3194
- 2 M. Bate  
**The mesoderm and its derivatives**  
M. Bate, A. Martinez Arias (Eds.), *The Development of *Drosophila melanogaster**, Cold Spring Harbor Laboratory Press, Cold Spring Harbor (1993), pp. 1013-1090

Feedback 

- 3 M. Bate, E. Rushton, D.A. Currie  
**Cells with persistent twist expression are the embryonic precursors of adult muscles in *Drosophila***  
Development, 113 (1991), pp. 79-89
- 4 R. Batty, A. Stevens, J.R. Jacobs  
**Axon repulsion from the midline of the *Drosophila* CNS requires slit function**  
Development, 126 (1999), pp. 2475-2481
- 5 M.K. Baylies, M. Bate, M. Ruiz Gomez  
**Myogenesis: A view from *Drosophila***  
Cell, 93 (1998), pp. 921-927  
[Article](#)  [PDF \(2MB\)](#)
- 6 M.K. Baylies, A. Martinez Arias, M. Bate  
***wingless* is required for the formation of a subset of muscle founder cells during *Drosophila* embryogenesis**  
Development, 121 (1995), pp. 3829-3837
- 7 S. Becker, G. Pasca, D. Strumpf, L. Min, T. Volk  
**Reciprocal signaling between *Drosophila* epidermal muscle attachment cells and their corresponding muscles**  
Development, 124 (1997), pp. 2615-2622
- 8 J.L. Bonkowski, S. Yoshikawa, D.D. O'Keefe, A.L. Scully, J.B. Thomas  
**Axon routing across the midline controlled by the *Drosophila* Derailed receptor**  
Nature, 402 (1999), pp. 540-544
- 9 C. Bourgoin, S.E. Lundgren, J.B. Thomas  
**Apterous is a *Drosophila* LIM domain gene required for the development of a subset of embryonic muscles**  
Neuron, 9 (1992), pp. 549-561  
[Article](#)  [PDF \(9MB\)](#)
- 10 M. Boutros, N. Paricio, D.I. Strutt, M. Mlodzik  
**Dishevelled activates JNK and discriminates between JNK pathways in planar polarity and wingless signaling**  
Cell, 94 (1998), pp. 109-118  
[Article](#)  [PDF \(672KB\)](#)
- 11 K.S. Broadie, M. Bate  
**The development of adult muscles in *Drosophila*: Ablation of identified muscle precursor cells**  
Development, 113 (1991), pp. 103-118
- 12 K.M. Cadigan, M.P. Fish, E.J. Rulifson, R. Nusse  
**Wingless repression of *Drosophila* frizzled 2 expression shapes the Wingless morphogen gradient in the wing**  
Cell, 93 (1998), pp. 767-777  
[Article](#)  [PDF \(905KB\)](#)
- 13 C.A. Callahan, J.L. Bonkowski, A.L. Scully, J.B. Thomas  
**derailed is required for muscle attachment site selection in *Drosophila***  
Development, 122 (1996), pp. 2761-2767
- 14 C.A. Callahan, M.G. Muralidhar, S.E. Lundgren, A.L. Scully, J.B. Thomas  
**Control of neuronal pathway selection by a *Drosophila* receptor protein-tyrosine kinase family member**  
Nature, 376 (1995), pp. 171-174
- 15 A. Carmona, S. Gisselbrecht, J. Harrison, F. Jimenez, A.M. Michelson  
**Combinatorial signaling codes for the progressive determination of cell fates in the *Drosophila* embryonic mesoderm**  
Genes Dev., 12 (1998), pp. 3910-3922
- 16 M. Crozatier, A. Vincent  
**Requirement for the *Drosophila* COE transcription factor Collier in formation of an embryonic muscle: Transcriptional response to notch signalling**  
Development, 126 (1999), pp. 1495-1504
- 17 M. Demerec  
**Biology of *drosophila***

A. Miller (Ed.), The Internal Anatomy and Histology of the Imago of *Drosophila melanogaster*, Cold Spring Harbor Laboratory Press, Cold Spring Harbor (1994)

- 18 C. Dohrmann, N. Azpiazu, M. Frasch  
**A new *Drosophila* homeo box gene is expressed in mesodermal precursor cells of distinct muscles during embryogenesis**  
Genes Dev., 4 (1990), pp. 2098-2111
- 19 J. Fernandes, M. Bate, K. Vijayraghavan  
**Development of the indirect flight muscles of *Drosophila***  
Development, 113 (1991), pp. 67-77
- 20 J.J. Fernandes, S.E. Celniker, K. VijayRaghavan  
**Development of the indirect flight muscle attachment sites in *Drosophila*: Role of the PS integrins and the stripe gene**  
Dev. Biol., 176 (1996), pp. 166-184  
[Article](#)  [PDF \(3MB\)](#)
- 21 G. Frommer, G. Vorbruggen, G. Pasca, H. Jackle, T. Volk  
**Epidermal egr-like zinc finger protein of *Drosophila* participates in myotube guidance**  
EMBO J., 15 (1996), pp. 1642-1649
- 22 A. Ghazi, S. Anant, K. VijayRaghavan  
**Apterous mediates development of direct flight muscles autonomously and indirect flight muscles through epidermal cues**  
Development, 127 (2000), pp. 5309-5318
- 23 M.S. Halfon, A. Carmena, S. Gisselbrecht, C.M. Sackerson, F. Jimenez, M.K. Baylies, A.M. Michelson  
**Ras pathway specificity is determined by the integration of multiple signal-activated and tissue-restricted transcription factors**  
Cell, 103 (2000), pp. 63-74  
[Article](#)  [PDF \(547KB\)](#)
- 24 M.S. Halfon, H. Keshishian  
**The Toll pathway is required in the epidermis for muscle development in the *Drosophila* embryo**  
Dev. Biol., 199 (1998), pp. 164-174  
[Article](#)  [PDF \(944KB\)](#)
- 25 V. Hatini, S. DiNardo  
**Distinct signals generate repeating striped pattern in the embryonic parasegment**  
Mol. Cell, 7 (2001), pp. 151-160  
[Article](#)  [PDF \(2MB\)](#)
- 26 G. Heide, K.G. Gotz  
**Optomotor control of course and altitude in *Drosophila melanogaster* is correlated with distinct activities of at least three pairs of flight steering muscles**  
J. Exp. Biol., 199 (1996), pp. 1711-1726
- 27 R.K. Ho, E.E. Ball, C.S. Goodman  
**Muscle pioneers: Large mesodermal cells that erect a scaffold for developing muscles and motoneurons in grasshopper embryos**  
Nature, 301 (1983), pp. 66-69
- 28 M. Ikeya, S. Takada  
**Wnt signaling from the dorsal neural tube is required for the formation of the medial dermomyotome**  
Development, 125 (1998), pp. 4969-4976
- 29 T. Jagla, F. Bellard, Y. Lutz, G. Dretzen, M. Bellard, K. Jagla  
**ladybird determines cell fate decisions during diversification of *Drosophila* somatic muscles**  
Development, 125 (1998), pp. 3699-3708
- 30 J. Jernvall, I. Thesleff  
**Reiterative signaling and patterning during mammalian tooth morphogenesis**  
Mech. Dev., 92 (2000), pp. 19-29  
[Article](#)  [PDF \(1MB\)](#)
- 31 Y. Kawasaki, T. Senda, T. Ishidate, R. Koyama, T. Morishita, Y. Iwayama, O. Higuchi, T. Akiyama

**Asef, a link between the tumor suppressor APC and G-protein signaling**

Science, 289 (2000), pp. 1194-1197

- 32 C.A. Keller, M.A. Grill, S.M. Abmayr

**A role for nautilus in the differentiation of muscle precursors**

Dev. Biol., 202 (1998), pp. 157-171

[Article](#)  [PDF \(1MB\)](#)

- 33 S. Knirr, N. Azpiazu, M. Frasch

**The role of the NK-homeobox gene *slouch* (S59) in somatic muscle patterning**

Development, 126 (1999), pp. 4525-4535

- 34 K.M. Kozopas, C.H. Samos, R. Nusse

**DWnt-2, a Drosophila Wnt gene required for the development of the male reproductive tract, specifies a sexually dimorphic cell fate**

Genes Dev., 12 (1998), pp. 1155-1165

- 35 S.G. Kramer, T. Kidd, J.H. Simpson, C.S. Goodman

**Switching repulsion to attraction: Changing responses to slit during transition in mesoderm migration**

Science, 292 (2001), pp. 737-740

- 36 P.A. Lawrence

**Cell lineage of the thoracic muscles of Drosophila**

Cell, 29 (1982), pp. 493-503

[Article](#)  [PDF \(11MB\)](#)

- 37 J.C. Lee, K. VijayRaghavan, S.E. Celniker, M.A. Tanouye

**Identification of a Drosophila muscle development gene with structural homology to mammalian early growth response transcription factors**

Proc. Natl. Acad. Sci. USA, 92 (1995), pp. 10344-10348

- 38 M. Leptin, T. Bogaert, R. Lehmann, M. Wilcox

**The function of PS integrins during Drosophila embryogenesis**

Cell, 56 (1989), pp. 401-408

[Article](#)  [PDF \(8MB\)](#)

- 39 B. Lilly, B. Zhao, G. Ranganayakulu, B.M. Paterson, R.A. Schulz, E.N. Olson

**Requirement of MADS domain transcription factor D-MEF2 for muscle formation in Drosophila**

Science, 267 (1995), pp. 688-693

- 40 J.N. Maloof, J. Whangbo, J.M. Harris, G.D. Jongeward, C. Kenyon

**A Wnt signaling pathway controls *hox* gene expression and neuroblast migration in *C. elegans***

Development, 126 (1999), pp. 37-49

- 41 B.S. Martin, M. Ruiz-Gomez, M. Landgraf, M. Bate

**A distinct set of founders and fusion-competent myoblasts make visceral muscles in the Drosophila embryo**

Development, 128 (2001), pp. 3331-3338

- 42 J.D. Masucci, R.J. Miltenberger, F.M. Hoffmann

**Pattern-specific expression of the Drosophila decapentaplegic gene in imaginal disks is regulated by 3' cis-regulatory elements**

Genes Dev., 4 (1990), pp. 2011-2023

- 43 Y. Mimori-Kiyosue, N. Shiina, S. Tsukita

**Adenomatous polyposis coli (APC) protein moves along microtubules and concentrates at their growing ends in epithelial cells**

J. Cell Biol., 148 (2000), pp. 505-518

- 44 J.A. Miyan, A.W. Ewing







**How Diptera move their wings: A re-examination of the wing base articulation and muscle systems concerned with flight**


Phil. Trans. R. Soc. London, 311 (1985), pp. 271-302

- 45 A.E. Munsterberg, J. Kitajewski, D.A. Bumcrot, A.P. McMahon, A.B. Lassar

**Combinatorial signaling by Sonic hedgehog and Wnt family members induces myogenic bHLH gene expression in the somite**

Genes Dev., 9 (1995), pp. 2911-2922

- 46 A. Nose, T. Isshiki, M. Takeichi  
**Regional specification of muscle progenitors in *Drosophila*: The role of the msh homeobox gene**  
Development, 125 (1998), pp. 215-223
- 47 L.A. O'Neill, C. Greene  
**Signal transduction pathways activated by the IL-1 receptor family: Ancient signaling machinery in mammals, insects, and plants**  
J. Leukoc. Biol., 63 (1998), pp. 650-657
- 48 M. Park, X. Wu, K. Golden, J.D. Axelrod, R. Bodmer  
**The wingless signaling pathway is directly involved in *Drosophila* heart development**  
Dev. Biol., 177 (1996), pp. 104-116  
[Article](#)  [PDF \(938KB\)](#)
- 49 O. Piepenburg, G. Vorbruggen, H. Jackle  
***Drosophila* segment borders result from unilateral repression of hedgehog activity by wingless signaling**  
Mol. Cell, 6 (2000), pp. 203-209  
[Article](#)  [PDF \(271KB\)](#)
- 50 G. Ranganayakulu, R.A. Schulz, E.N. Olson  
**Wingless signaling induces nautilus expression in the ventral mesoderm of the *drosophila* embryo**  
Dev. Biol., 176 (1996), pp. 143-148  
[Article](#)  [PDF \(387KB\)](#)
- 51 M.C. Reedy, C. Beall  
**Ultrastructure of developing flight muscle in *Drosophila*. II. Formation of the myotendon junction**  
Dev. Biol., 160 (1993), pp. 466-479  
[Article](#)  [PDF \(2MB\)](#)
- 52 P.K. Rivlin, A.M. Schneiderman, R. Booker  
**Imaginal pioneers prefigure the formation of adult thoracic muscles in *Drosophila melanogaster***  
Dev. Biol., 222 (2000), pp. 450-459  
[Article](#)  [PDF \(975KB\)](#)
- 53 M. Ruiz-Gomez, M. Bate  
**Segregation of myogenic lineages in *Drosophila* requires numb**  
Development, 124 (1997), pp. 4857-4866
- 54 M. Ruiz-Gomez, N. Coutts, A. Price, M.V. Taylor, M. Bate  
***Drosophila* dumbfounded: A myoblast attractant essential for fusion**  
Cell, 102 (2000), pp. 189-198  
[Article](#)  [PDF \(416KB\)](#)
- 55 M. Ruiz-Gomez, S. Romani, C. Hartmann, H. Jackle, M. Bate  
**Specific muscle identities are regulated by Kruppel during *Drosophila* embryogenesis**  
Development, 124 (1997), pp. 3407-3414
- 56 E. Rushton, R. Drysdale, S.M. Abmayr, A.M. Michelson, M. Bate  
**Mutations in a novel gene, *myoblast city*, provide evidence in support of the founder cell hypothesis for *Drosophila* muscle development**  
Development, 121 (1995), pp. 1979-1988
- 57 J. Russell, A. Gennissen, R. Nusse  
**Isolation and expression of two novel Wnt/wingless gene homologues in *Drosophila***  
Development, 115 (1992), pp. 475-485
- 58 H.M. Stern, A.M. Brown, S.D. Hauschka  
**Myogenesis in paraxial mesoderm: Preferential induction by dorsal neural tube and by cells expressing Wnt-1**  
Development, 121 (1995), pp. 3675-3686
- 59 S. Tajbakhsh, U. Borello, E. Vivarelli, R. Kelly, J. Papkoff, D. Duprez, M. Buckingham, G. Cossu  
**Differential activation of *Myf5* and *MyoD* by different Wnts in explants of mouse paraxial mesoderm and the later activation of myogenesis in the absence of *Myf5***  
Development, 125 (1998), pp. 4155-4162

- 60 S.J. Vainio, M.S. Uusitalo  
**A road to kidney tubules via the Wnt pathway**  
Pediatr. Nephrol., 15 (2000), pp. 151-156
- 61 T. Volk, K. VijayRaghavan  
**A central role for epidermal segment border cells in the induction of muscle patterning in the Drosophila embryo**  
Development, 120 (1994), pp. 59-70
- 62 G. Vorbruggen, H. Jackle  
**Epidermal muscle attachment site-specific target gene expression and interference with myotube guidance in response to ectopic stripe expression in the developing Drosophila epidermis**  
Proc. Natl. Acad. Sci. USA, 94 (1997), pp. 8606-8611
- 63 X. Wu, K. Golden, R. Bodmer  
**Heart development in Drosophila requires the segment polarity gene wingless**  
Dev. Biol., 169 (1995), pp. 619-628  
[Article](#)  [PDF \(933KB\)](#)
- 64 T. Yamitzky, L. Min, T. Volk  
**The Drosophila neuregulin homolog Vein mediates inductive interactions between myotubes and their epidermal attachment cells**  
Genes Dev., 11 (1997), pp. 2691-2700

1 To whom correspondence should be addressed. E-mail: kozopas@hotmail.com.

Copyright © 2002 Elsevier Science (USA). All rights reserved.

**ELSEVIER**

[About ScienceDirect](#) [Remote access](#) [Shopping cart](#) [Contact and support](#) [Terms and conditions](#) [Privacy policy](#)

Cookies are used by this site. For more information, visit the [cookies page](#).

Copyright © 2017 Elsevier B.V. or its licensors or contributors. ScienceDirect ® is a registered trademark of Elsevier B.V.

 **RELX** Group™