logical systems. Osmotic swelling of cytoplasmic vesicles could, in principle, occur through a number of mechanisms, including mobilization of osmotically inactive constituents in the vesicle, alteration of vesicle membrane permeability to ions, or stimulation of ion pumping into the vesicles. In the experiment represented in Fig. 1B, osmotic swelling of the vesicle was accomplished by substituting a permeant solute (glucose) for a nonpermeant one (stachyose). This is formally equivalent to a biological vesicle osmotically swelling because of an increase in the permeability of its membrane to cytosolic constituents, such as ions.

Numerous examples already exist of vesicle swelling being associated with exocytosis (although it is not yet clear that the swelling precedes fusion). Among these are mucocyst discharge in *Tetrahymena* (*13*), serotonin release by mast cell granules (*14*), and granular discharge by *Limulus* amoebocytes (*15*). It has also been shown that antidiuretic hormone–stimulated fusion of cytoplasmic tubular vesicles with the luminal plasma membrane of toad urinary bladder can be regulated by osmotic forces in a manner consistent with that of vesicle–planar membrane fusion (*16*). Although in our system Ca^{2+} stimulates fusion by promoting the close association of vesicle and planar membranes, this need not be its role (or its only role) in biological exocytosis. The possibility that increased levels of Ca^{2+} trigger fusion by stimulating osmotic swelling of vesicles (by any of the mechanisms mentioned above) merits serious consideration.

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References and Notes

1. B. Katz, *The Release of Neural Transmitter Substances* (Liverpool Univ. Press, Liverpool, England, 1969).
2. W. W. Douglas, *Biochem. Soc. Symp.* **39**, 1 (1974).
3. G. Palade, *Science* **189**, 347 (1975).
4. J. B. Wade, *Curr. Top. Membr. Transp.* **13**, 123 (1980).
5. D. Epel and V. D. Vacquier, in *Membrane Fusion*, G. Poste and G. L. Nicolson, Eds. (Elsevier/North-Holland, Amsterdam, 1978), p. 1.
6. J. Zimmerberg, F. S. Cohen, A. Finkelstein, *J. Gen. Physiol.* **75**, 241 (1980).
7. F. S. Cohen, J. Zimmerberg, A. Finkelstein, *ibid.*, p. 251.
8. J. Zimmerberg, F. S. Cohen, A. Finkelstein, *Science* **210**, 906 (1980).
9. H. Schindler and J. P. Rosenbusch, *Proc. Natl. Acad. Sci. U.S.A.* **75**, 3741 (1978).
10. M. Akabas, F. S. Cohen, A. Finkelstein, in preparation.
11. H. Naikaido and E. Y. Rosenberg, *J. Gen. Physiol.* **77**, 121 (1981).
12. C. Miller and E. Racker, *J. Membr. Biol.* **30**, 283 (1976).
13. B. Satir, C. Schooley, P. Satir, *J. Cell Biol.* **56**, 153 (1973).
14. W. W. Douglas, quoted in H. B. Pollard, K. Tack-Goldman, C. J. Pazoles, C. E. Creutz, N. R. Shulman, *Proc. Natl. Acad. Sci. U.S.A.* **74**, 5295 (1977).
15. R. L. Ornberg and T. S. Reese, *J. Cell Biol.* **90**, 40 (1981).
16. W. A. Kachadorian, J. Muller, A. Finkelstein, *ibid.* **91**, 584 (1981).
17. M. Montal, *Methods Enzymol.* **32**, 545 (1974).
18. Y. Kagawa and E. Racker, *J. Biol. Chem.* **246**, 5477 (1971).
19. J. Reyes and R. Latorre, *Biophys. J.* **28**, 259 (1979).
20. F. Olson, C. A. Hunt, F. C. Szoka, W. J. Vail, D. Papahadjopoulos, *Biochim. Biophys. Acta* **557**, 9 (1979).
21. J. P. Rosenbusch, *J. Biol. Chem.* **249**, 8019 (1974).
22. This work was supported by NIH grants GM29210-05, 5T32GM7288, and GM 27367-02.

29 April 1982; revised 4 June 1982

Rotating Shift Work Schedules That Disrupt Sleep Are Improved by Applying Circadian Principles

Abstract. *Workers on rotating shifts dislike those aspects of their work schedules that violate circadian sleep-wake cycle physiology. Work schedule satisfaction, subjective health estimates, personnel turnover, and worker productivity improve when schedules are introduced that are designed to incorporate circadian principles.*

The human sleep-wake cycle has evolved on a rotating planet with a regular 24-hour alternation between day and night. Yet within the past 50 years, the need for round-the-clock operations in many industrial plants and emergency services has led to major changes in the day-night schedules to which 26.8 percent of the U.S. work force is exposed, many of whom work shifts which rotate between night, evening, and daytime duties (*1*).

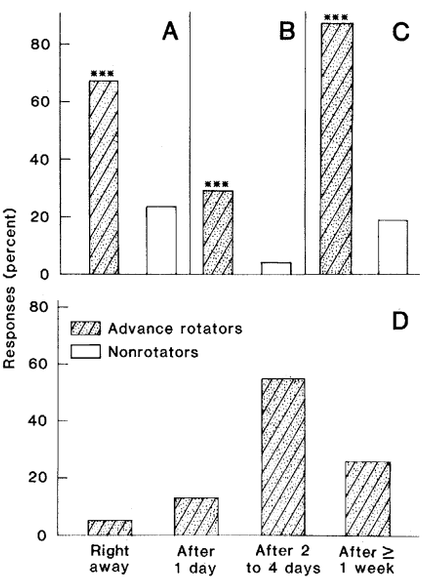

Fig. 1. (A to C) Comparison of sleep-wake cycle questionnaire responses from workers on weekly phase advance rotating shifts and nonrotating day and swing shift workers. The rotating shift workers reported greater problems with (A), poor quality sleep, $\chi^2(1) = 26.4$, $P < .001$; (B), falling asleep at work, $\chi^2(1) = 15.6$, $P < .001$; and (C), the schedule changing too often, $\chi^2(1) = 55.0$, $P < .001$. (D) The number of days taken for the sleep time of the weekly phase advance rotating shift workers to adjust after each shift rotation. ***$P < .001$.

Numerous medical and psychosocial problems associated with rotating shift work schedules have been reported (*2*), and several different approaches to the problems have been suggested (*3*, *4*). Because research findings (*5*–*7*) indicated to us that most rotating work schedules are outside the range of entrainment of the pacemaker timing the human circadian sleep-wake cycle, we postulated that a practical and effective intervention would be to resolve this aspect of the shift work problem. We report that rotating shift workers are often dissatisfied with the features of their schedules that violate circadian principles, and that when schedules are introduced which take into account the properties of the human circadian system, subjective estimates of work schedule satisfaction and health improve, personnel turnover decreases, and worker productivity increases.

We compared 85 male rotating shift workers, aged 19 to 68 (mean ± standard deviation, 31.4 ± 10.0), with a control group of 68 male nonrotating day and swing shift workers with comparable jobs, aged 19 to 56 (mean, 27.3 ± 8.2), at the Great Salt Lake Minerals and Chemicals Corporation in Ogden, Utah (*8*). For 10 years at this plant, weekly shifts were rotated with each crew working a given 8-hour shift for 7 days before rotating to the preceding 8-hour shift. Hence the scheduled work time rotated in a phase advancing direction from night (midnight to 8 a.m.) to swing (4 p.m. to midnight) to day (8 a.m. to 4 p.m.) shift (*9*).

Each worker was given the job de-

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scriptive and health indices of Smith, Kendall, and Hulin (*10*), and sleep-wake and schedule preference questionnaires. The response rate was 84 percent (*11*). The rotators reported significantly more [$\chi^2(1) = 26.4$, $P < .001$] problems with insomnia than did nonrotators (Fig. 1A) and 29 percent of the rotators reported that they had fallen asleep at work at least once during the previous 3 months (Fig. 1B). A major complaint was that the schedule changed too often (Fig. 1C), and 81 percent reported that it took 2 to 4 days or more for their sleep schedule to adjust after each phase advance; this included 26 percent who said they were never able to adjust before being rotated again (Fig. 1D).

To design a rotating work schedule that would take into account the properties of the circadian timing system, we focused on two key issues: the direction of rotation and the interval between phase shifts. In normal human subjects the endogenous free-running period of the sleep-wake cycle averages 25 hours, but that cycle can usually be entrained by periodic environmental time cues which are within 1 to 2 hours of the endogenous period (*6*). Thus the typical range of entrainment in man easily accommodates normal synchronization to the 24-hour period of the earth's rotation. This range allows in any one cycle only a small phase advance with respect to environmental time but a 2- to 3-hour phase delay (*12*). This explains why adaptation is more rapid after westbound travel (requiring a phase delay) than after eastbound travel (requiring a phase advance) (*13*). These considerations led us to conclude that work schedules that rotate should do so by successive phase delays and that the interval between phase shifts should be as great as is practical.

To test this hypothesis, we divided shift workers on phase advancing work schedules into two groups and placed them on phase delay schedules: 33 workers continued to change shifts each week and 52 others rotated shifts by phase delay once every 21 days (*14*). Before implementation of the schedule, all workers and managers attended an audiovisual presentation on the basic properties of the circadian sleep-wake cycle that had suggestions for adjusting their sleep time to their schedule, and each received an educational booklet designed for the workers at this facility.

The workers' preferences were evaluated from questionnaires distributed 3 months after the introduction of the new schedules (Fig. 2, A to D), and personnel

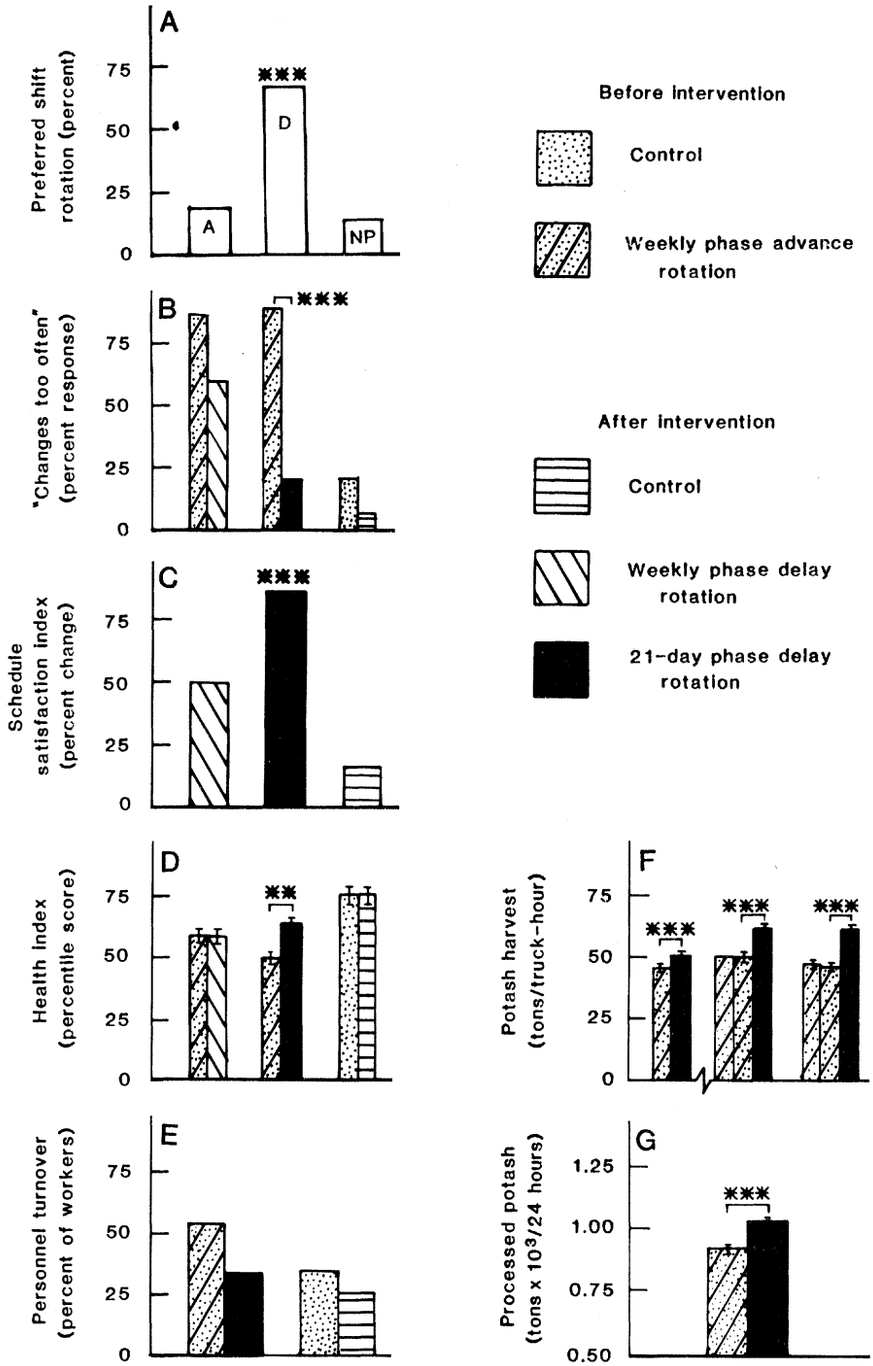

Fig. 2. Measures of worker satisfaction and productivity before and after introduction of new shift work schedules. (A) After experience with both schedules, workers preferred delay (*D*) rotating schedules over the advance (*A*) rotating schedule [$\chi^2(2) = 43.6$, $P < .001$]; *NP*, no preference. (B) There was a significant reduction [$\chi^2(1) = 47.8$, $P < .001$] in the complaint that the schedule "changes too often" by rotators on the 21-day phase delay schedule but not by rotators on the weekly phase delay schedule or by controls. (C and D) Rotators on the 21-day phase delay schedule had significantly increased scores on both the schedule satisfaction index and on the health index [$t(51) = 4.86$, $P < .001$, and $t(51) = 3.23$, $P < .01$, respectively]. (E) Personnel turnover rate during the 9-month study period among rotating shift workers (left) was reduced (after the 21-day phase delay schedule was introduced) to the same range as a comparable control group of nonrotating shift workers (right). (F) Potash harvesting productivity increased significantly (Student's *t*-test) during the quarter season immediately following the introduction of the 21-day phase delay rotating schedule [$t(103) = 3.49$, $P < .001$] (left cluster); compared to the previous 2 years there were also increases in the first [$t(96) = 7.58$, $P < .001$] and second [$t(99) = 10.89$, $P < .001$] quarters after the summer break (middle and right clusters) (*11, 12*). (G) The production of processed potash increased significantly [$t(398) = 6.99$, $P < .001$] after introduction of the 21-day phase delay rotation schedule in comparison with the same period the previous year when the workers were on the weekly phase advance schedule. $^{**}P < .01$; $^{***}P < .001$.

turnover and plant productivity were analyzed 9 months after the introduction of the new schedules (Fig. 2, E to G) (*15*). The workers clearly preferred the phase delay direction of rotation (Fig. 2A); complaints that the schedule changed too often dropped from 90 to 20 percent among the workers on the 21-day phase delay rotation schedule (Fig. 2B). This was associated with a substantial increase on the schedule satisfaction index (Fig. 2C), improvements in the health index (Fig. 2D), and a reduction in personnel turnover (Fig. 2E) (*16*). At the same time, the rate of potash harvesting (Fig. 2F) by men operating front-end loaders in the evaporation ponds and the rate of processed potash production in the plant (Fig. 2G) also increased after the introduction of the new schedule, and the increases in productivity were maintained in the harvest season which followed the completion of our study period (*17, 18*).

Previously three major strategies have been used to address the problems of adaptation to shift work. The first, and perhaps most obvious, is to schedule workers on straight shifts without rotation. However, it is often difficult to staff the night shift, and straight shift scheduling still results in conflicting environmental synchronizers for the night worker who adopts daytime activities for social reasons on days off. The second strategy, favored in Europe, is to rotate from one shift to the next rapidly in order to escape the consequences of partial temporal adaptation (*3*). However, the circadian system may be affected, even on rapid rotation regimens, since a change from the phase advance to the phase delay direction of a rapid rotation system resulted in some improvements in both psychological and physiological measures (*19*). A third strategy would be to take advantage of differences between individuals in measurable properties of the circadian timing system, such as rhythm amplitude (*4*), to select individuals with the greatest tolerance for working or sleeping on abnormal schedules.

In contrast, our strategy was to take advantage of those properties of the circadian system that individuals share in common: the longer than 24-hour endogenous period and the limited range of entrainment. The results of this field study indicate that work schedules that rotate by phase delay with an extended interval between each rotation are most compatible with the properties of the human circadian timing system. However, the design of any specific work schedule must, of course, take into consideration both the nature of the work and the specific needs of the workers.

The improvements recorded on the 21-day phase delay schedule are consistent with the results of temporal isolation and clinical studies (*5, 6, 12, 20*). Mills *et al.* (*20*) showed that the circadian rhythms of volunteers usually show a phase delay of 16 hours in response to an 8-hour phase advance shift of schedule because such an abrupt phase advance is beyond the usual human range of entrainment (*6*). Most workers on phase advancing schedules may therefore be in a state of continual forced internal desynchronization (*13, 21*) between the pacemakers (*7, 22*) of their circadian system.

The consequences of such disruption in temporal organization are just beginning to be understood. It was only recently recognized, for example, that the normal timing and organization of sleep depend on an appropriate phase relation between circadian pacemakers (*5, 23*). The forced disruption of phase relations inherent in shift work schedules accounts for the previously unexplained sleep disturbances reported in earlier field studies (*24*). Failures in homeostatic regulatory mechanisms are also associated with internal desynchronization of the circadian system (*25*), and chronic external desynchronization induced by light-dark phase shifts results in decreases of 5 to 20 percent in longevity in insects (*26*) and in mammals (*27*). In humans, the long-term effects of such phase shifts are not known, but field studies indicate that there are more sleep and digestive disorders among workers on rotating shifts (*2*), with some unable to tolerate the schedules (*28*). Concern about the possible long-term health consequences of rotating shifts is growing (*29*). It may be that the application of circadian principles to the design of schedules can maintain the temporal integrity of the circadian system and minimize for the shift worker any detrimental consequences of circadian disruption.

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References and Notes

1. M. J. Colligan, in *The Twenty-Four Hour Workday*, L. C. Johnson, D. I. Tepas, W. P. Colquhoun, M. J. Colligan, Eds. [Department of Health and Human Services (NIOSH) Publ. No. 81-127, Government Printing Office, Washington, D.C., 1981], pp. 261–268.
2. J. Rutenfranz, W. P. Colquhoun, P. Knauth, J. N. Ghata, *Scand. J. Work Environ. Health* **3**, 165 (1977); Japan Association of Industrial Health, *J. Sci. Labour* **55**, 1 (1979); J. T. Saldivar, S. M. Hoffman, C. E. Melton, *Sleep in Air Traffic Controllers* (Rep. No. FAA-AM-77-5, Department of Transportation, Washington, D.C., 1977); A. Reinberg, Ed. "Chronobiological field studies of oil refinery shift workers," *Chronobiologica* **6** (Suppl. 1) (1979).
3. J. Rutenfranz, P. Knauth, W. P. Colquhoun, *Ergonomics* **19**, 331 (1976); T. Åkerstedt and L. Torsvall, *ibid.* **21**, 849 (1978); S. Folkard, in *Chronobiology: Principles and Applications to Shifts in Schedules*, L. E. Scheving and F. Halberg, Eds. (Sijthoff & Noordhoff, Alphen aan den Rijn, Netherlands, 1980), pp. 293–306; Z. Vokac, P. Magnus, E. Jebens, N. Gundersen, *Int. Arch. Occup. Environ. Health* **49**, 53 (1981).
4. J. Aschoff, *Ergonomics* **21**, 739 (1978); A. Reinberg, N. Vieux, J. Ghata, A.-J. Chaumont, A. Laporte, *ibid.*, p. 763.
5. C. A. Czeisler, thesis, Stanford University (1978); _____, E. D. Weitzman, M. C. Moore-Ede, J. C. Zimmerman, R. S. Knauer, *Science* **210**, 1264 (1980).
6. R. A. Wever, *The Circadian System of Man* (Springer-Verlag, New York, 1979).
7. M. C. Moore-Ede, F. M. Sulzman, C. A. Fuller, *The Clocks That Time Us: Physiology of the Circadian Timing System* (Harvard Univ. Press, Cambridge, Mass., 1982).
8. This was a nonhomogeneous work force from both urban and rural settings; many had moved to the area from surrounding states such as California, Idaho, and Nevada because of economic opportunity.
9. In keeping with circadian terminology, we use phase advances ($+\Delta\phi$) to mean shifts to an earlier hour on the reference time scale (in this case, local clock time) and phase delays ($-\Delta\phi$) to mean shifts to a later hour.
10. P. C. Smith, L. M. Kendall, C.L. Hulin, *The Measurement of Satisfaction in Work and Retirement* (Rand McNally, Chicago, 1969).
11. For assessments of the effects of our intervention, only rotators who completed both initial and follow-up assessments were included (93 percent of initial subjects).
12. C. A. Czeisler, G. S. Richardson, R. M. Coleman, J. C. Zimmerman, M. C. Moore-Ede, W. C. Dement, E. D. Weitzman, *Sleep* **4**, 1 (1981).
13. K. E. Klein and H. M. Wegmann, in *Sleep, Wakefulness and Circadian Rhythms*, A. N. Nicholson, Ed. (Publ. No. 105, NATO Advisory Group for Aerospace Research and Development, Neuilly sur Seine, France, 1979), pp. 10.1–10.25.
14. The 21-day phase delay schedule was originally designed so that work hours were shifted gradually by 1 to 2 hours per day for 5 days until the new shift time was attained. This procedure was eliminated after a month when it proved inconvenient for the workers' family life and car pooling arrangements; thereafter an 8-hour phase delay was undertaken on every 21st day.
15. Rotating shift schedules for these workers generally operated during the potash harvest season from September through May. During the summer, most workers work straight day shifts.
16. That these effects are due to increased tolerance of the circadian system to the work schedule is supported by the fact that there was little improvement in other factors, such as indices of interference with family or social life.
17. It is unlikely that these increases in productivity reflected the presence of the study team since (i) productivity statistics were derived by retrospective analysis of company data that was routinely gathered; (ii) hourly pay scales were not linked to individual or group productivity; and (iii) the increases in productivity persisted throughout a 6-month follow-up after departure of the study team [H. M. Parsons, *Science* **183**, 922 (1974)].
18. A time and motion analysis by a company operations engineer revealed that the modification and replacement of one of the harvesting machines during the summer of 1981 may have contributed up to 4 percent of the increase in productivity in the first and second quarters after the summer break (Fig. 2F, middle and right clusters), but this could not explain the increase in the quarter before the summer break

(Fig. 2F, left cluster), nor for more than a fraction of the increases in the subsequent quarters.
19. Institute of Medicine, *Research on Stress and Human Health* (National Academy Press, Washington, D.C., 1981), p. 105.
20. J. N. Mills, D. S. Minors, J. M. Waterhouse, *J. Physiol. (London)* **285**, 455 (1978).
21. J. Aschoff, in *Environmental Endocrinology*, I. Assenmacher and D. Farner, Eds. (Springer-Verlag, New York, 1978), pp. 185–195.
22. B. Rusak and I. Zucker, *Physiol. Rev.* **59**, 449 (1979); C. A. Fuller, R. Lydic, F. M. Sulzman, H. E. Albers, B. Tepper, M. C. Moore-Ede, *Am. J. Physiol.* **241**, R385 (1981); R. Lydic, W. C. Schoene, C. A. Czeisler, M. C. Moore-Ede, *Sleep* **2**, 355 (1980).
23. J. Zulley, R. Wever, J. Aschoff, *Pfluegers Arch.* **391**, 314 (1981); T. Åkerstedt and M. Gillberg, in *The Twenty-Four Hour Workday*, L. C. Johnson, D. I. Tepas, W. P. Colquhoun, M. J. Colligan, Eds. [Department of Health and Human Services (NIOSH) Publ. No. 81-127, Government Printing Office, Washington, D.C., 1981], pp. 605–624; R. E. Kronauer, C. A. Czeisler, S. F. Pilato, M. C. Moore-Ede. E. D. Weitzman, *Am. J. Physiol.* **242**, R3 (1982).
24. J. Foret and G. Lantin, in *Aspects of Human Efficiency*, W. P. Colquhoun, Ed. (English Univ. Press, London, 1972), pp. 273–282.
25. C. A. Fuller, F. M. Sulzman, M. C. Moore-Ede, *Science* **199**, 794 (1978).
26. J. Aschoff, U. Saint-Paul, R. Wever, *Naturwissenschaften* **58**, 574 (1971).
27. F. Halberg, W. L. Nelson, L. Cadotte, *Int. Conf. Proc. Int. Soc. Chronobiol.* **12**, 133 (1977).
28. A. Aanonsen, *Ind. Med. Surg.* **28**, 422 (1959).
29. L. C. Johnson, D. I. Tepas, W. P. Colquhoun, M. J. Colligan, Eds., *Variations in Work-Sleep Schedules: Effects on Health and Performance* (Spectrum, New York, 1981); D. A. Hamburg, G. R. Elliott, D. L. Parron, Eds., *Health and Behavior* (Institute of Medicine, National Academy Press, Washington, D.C., 1982), pp. 108–123.
30. We thank the workers for their participation; P. L. Richey for his role in establishing and helping coordinate this project; the company management and staff for their cooperation; D. Armor, K. R. Faubel, A. Forrest, M. M. Testa, and D. C. Watson for assistance with data analysis; B. H. Colyear III, S. Lawson, J. M'Guinness, and H. Wilson for preparation of illustrations; L. C. Kilham, J. Nitzsche, and K. T. Redding for manuscript preparation; J. I. Thompson for editing of educational materials; and D. A. Hamburg for his review of the manuscript.
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8 February 1982; revised 26 April 1982

Deficiency of Functional Messenger RNA for a Developmentally Regulated β-Crystallin Polypeptide in a Hereditary Cataract

Abstract. *The messenger RNA for a β-crystallin polypeptide with a molecular size of 27 kilodaltons, first detected 5 to 10 days after birth in the normal mouse lens and the Nakano mouse cataract, was not detected in the Philly mouse cataract with translation in vitro. The heterozygous Philly lens had intermediate levels of the 27-kilodalton β-crystallin polypeptide and exhibited delayed onset of the cataract. The deficiency of functional 27-kilodalton β-crystallin messenger RNA is the earliest lesion reported yet for the Philly lens and points to a transcriptional or posttranscriptional developmental defect in this hereditary cataract.*

Development of the ocular lens is characterized by differential synthesis of the crystallins (structural proteins) and is consequently a favorable system for the study of differential gene expression in eukaryotic cells (*1*). Normally the lens is transparent. In certain strains of mice, however, the lens becomes opaque—cataractous—after birth. The Philly mouse, a derivative of the Swiss-Webster strain, develops an osmotic cataract during the fourth postnatal week (*2*). The Philly cataract progresses from an initial faint subcapsular opacity to a dense nuclear cataract in about 1 month (*3*). Crystallin synthesis is severely depressed in the fiber cells of the Philly cataract (*4*). This appears to be caused, at least in part, by ionic changes within the lens that interfere with the translation of crystallin messenger RNA's (mRNA's) (*5*). Prior to the general reduction in crystallin synthesis, a β-crystallin polypeptide with a molecular size near 27 kilodaltons (27 K) is selectively missing from the Philly cataract (*6*). We now report that this β-crystallin polypeptide is a developmentally regulated protein whose mRNA cannot be detected by translation in vitro until the second week after birth for the normal Swiss-Webster mouse and cannot be detected at all by translation in vitro for the Philly mouse.

The polypeptide compositions of normal Swiss-Webster and Philly mouse lenses were examined by sodium dodecyl sulfate–polyacrylamide gel electrophoresis (Fig. 1). The arrows in Fig. 1 point to the 27 K β-crystallin polypeptide band. This band of protein was not present in the normal Swiss-Webster lens at day 1 or day 5 but was easily visible by day 10 and accumulated thereafter. In contrast, the 27 K β-crystallin polypeptide appeared to be missing from the Philly lens at all stages examined. Experiments were not performed on older mice because β-crystallins degrade during the process of opacification (*4*, *6*).

A trace of the 27 K β-crystallin polypeptide was observed as early as days 1 and 5 after birth, and considerable amounts were evident by the tenth postnatal day in the BALB/c and Nakano lenses (Fig. 1). Nakano mice were derived originally from BALB/c mice. The Nakano mouse develops a hereditary osmotic cataract associated with ionic imbalances (*7*) caused by the production of an inhibitor of the cellular Na,K-adenosine triphosphatase (*8*). Thus the time of appearance for the 27 K β-crystallin polypeptide may vary slightly with the strain of mouse. Moreover, the deficiency in the 27 K β-crystallin polypeptide is not due to general osmotic imbalances.

Total RNA's extracted from the lenses of Philly and control mice were tested by translation in a reticulocyte lysate to determine whether the Philly lens lacks a functional mRNA for the 27 K β-crystallin polypeptide. Autoradiograms of sodi-

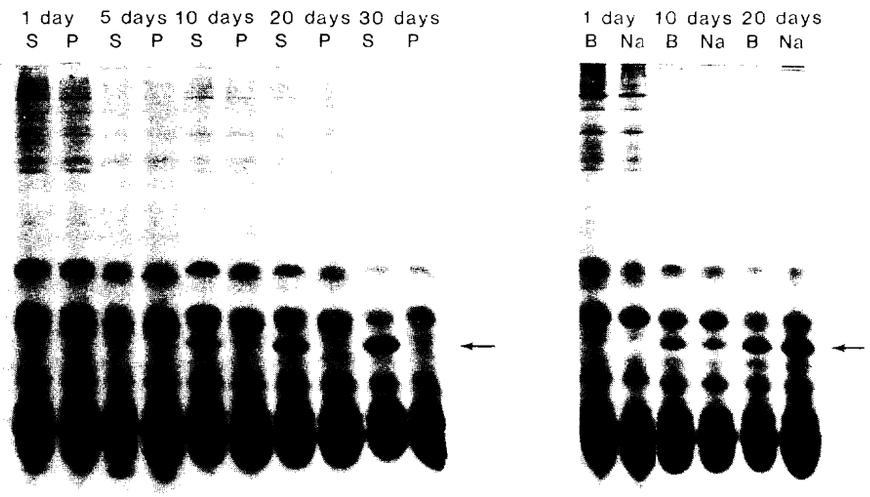

Fig. 1. Sodium dodecyl sulfate–polyacrylamide gels of lens proteins from Swiss-Webster control (*S*), Philly (*P*), BALB/c (*B*), and Nakano (*Na*) lenses. The lenses were removed from the eyes and homogenized in 10 m*M* 2-mercaptoethanol, 1 m*M* EDTA, and 1 percent sodium dodecyl sulfate. Samples of total lens protein (35 μg) were subjected to electrophoresis in a 15 percent polyacrylamide slab gel (*13*). Gels were stained with Coomassie brilliant blue R (Bio-Rad). The arrows point to the 27 K β-crystallin polypeptide; other small differences between the control and Philly lens proteins were not reproducible.

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