JOURNAL OF THE TENNESSEE ACADEMY OF SCIENCE
Volume 30, Number 4, October, 1955

SOME ABNORMALITIES FOUND IN TAIL-SHORT HETEROZYGOTES

WALTER C. MORGAN
South Dakota State College, Brookings

In *Mus musculus* the dominant mutation, Tail-short, has as its most obvious effect a shortening of the tail (to less than one-half normal length in most instances). As reported by Morgan (1950) there is also a slight shortening of the body in the heterozygotes. The other skeletal anomaly reported in Tail-short mice involved an elongation of the pollex in approximately five percent of the mutants. It has recently been observed in prepared specimens, that there are other bone abnormalities in the mutants. Additional skeletal abnormalities which are attributable primarily to the presence of *Ts* are here reported for three groups of mutants: I, Strain "C"; II, Bagg albino hybrids; and III, Outcross hybrids. In all of these groups variable abnormalities of the skull, the thoracic basket, and the vertebral column are described.

MATERIALS AND METHODS

The first group of animals, referred to as Group I, was from the highly inbred strain "C" stock within which the mutant had arisen. Mice analyzed in Group I were at F_{74} and F_{75}; the mutation arose at F_{63}.

Group II consisted of mice which arose from crossing strain "C" F_{74} animals with Bagg albinos at F_{85}. Strain "C" originated many years ago from the Bagg albino stock and has been treated as a subline. Consequently, if any differences exist between the Bagg albino stock and Strain "C" stock, they would be attributable to selection and possible mutations since the separation of strain "C".

Group III animals resulted from the outcrossing of strain "C" Tail-short mice to entirely unrelated hybrids. The mutants in this group were those which were phenotypically similar to the other two groups, except that some had longer tails.

All mice reported were at least two months old. The technique employed in the preparation of skeletons was to kill, skin, and eviscerate the specimen. The tissue was then macerated in 2% KOH for three to six days. This was followed by staining in a dilute solution of Alizarin Red S for four to six days and finally preserving the specimen in glycerine. Specimens were examined through an elongate glass container. Gross abnormalities were recorded and, in a few instances, appendages were removed to permit more careful examination of the ribs.

Terminology for this report will involve use of the following symbols: Ce = cervical, T = thoracic, L = lumbar, S = sacral, Ca = caudal, R = rib and St = sternebra. Numbering is from the anterior end to the posterior (i.e., atlas = Ce-1 and axis = Ce-2).

TABLE 1

SKELETAL OBSERVATIONS OF 65 HETEROZYGOTES

Region	*Sex*	*Group I* nor.	*Group I* abn.	*Group II* nor.	*Group II* abn.	*Group III* nor.	*Group III* abn.
Sacral	males	3	3	4	5	8	10
	females	1	6	3	1	7	6
	total	4	9	7	6	15	16
Lumbar	males	7	1	10	0	16	3
	females	10	0	5	0	13	0
	total	17	1	15	0	29	3
Thoracic	males	4	4	3	7	14	5
	females	5	5	4	1	9	4
	total	9	9	7	8	23	9
Ribs	males	6	2	8	2	12	7
	females	8	2	3	2	8	5
	total	14	4	11	4	20	12
Sternum	males	5	2	3	6	8	11
	females	1	8	2	3	10	3
	total	6	10	5	9	18	14
Cervical	males	4	2	6	4	12	7
	females	4	1	1	2	7	6
	total	8	3	7	6	19	13

OBSERVATIONS

The common vertebral pattern was 7 cervicals, 13 thoracics (in normals) and 14 thoracics (in mutants), 6 lumbars, 4 sacrals and 30 caudals (in normals). Carter (1951) refers to the pattern of 7-13-6 as the prevailing presacral scheme for most mouse stocks.

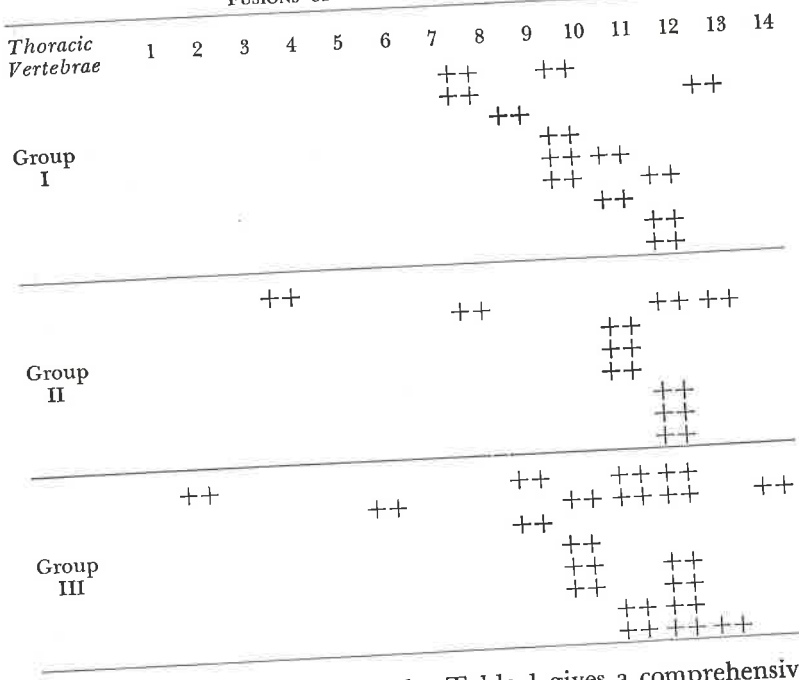
A few general comments will precede the more detailed discussion of the three groups of specimens. Usually there was no elevation of the T-2 vertebral spine. The prominent spine is common in many stocks (Morgan, 1954) and was occasionally observed in Tail-short specimens. However, the incidence in mutants was not significantly higher than that for normal-tailed mice from the same sublines.

The other generalizations involve phenomena peculiar to the mutants. Tail-short mice were shorter than were the normals. In addition to caudal and sacral compressions there were conspicuous compressions in the cervical and often in the thoracic regions. The anterior compression was correlated with thinner vertebrae which were occasionally fused. An obvious shortening and apparent broadening of the skulls of mutants was also observed.

A total of 65 mutants were analyzed in the three groups which follow. All had abnormal tails and only seven had no presacral abnormalities. Eighteen normal-tailed mice from the

TABLE 2

FUSIONS OF THORACIC VERTEBRAE



same sublines served as controls. Table 1 gives a comprehensive summary of the observed abnormalities.

Group I

In Table 1, skeletal data from these ten females and eight males are summated. The caudal vertebrae of 15 mice were irregularly fused and shortened to an extreme, such that less than four vertebrae could be separately distinguished. The lumbar vertebrae (5.6% abnormal) were affected less by *Ts* than were any other analyzed sectors. (In all of the mutant

groups studied fewer mice had abnormal lumbar vertebrae than had abnormalities in cervical, thoracic, sacral or caudal vertebrae.)

Some of the most interesting abnormalities were found in the thoracic region. The sector which was most frequently involved was between T-9 and T-12, as shown in Table 2. Dyssymphysis of T-2 was also observed in one female. In addition to these deformities there were numerous lesions of the ribs and sterna. Two females and two males had rib abnormalities. The numerical identity of the affected ribs is given in Table 3. Two of the mice with abnormal ribs also had abnor-

TABLE 3

LOCATION OF ABNORMAL RIB FUSIONS

Ribs	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Group I			++	++		++	++							
							++							
Group II			++											
			++				++							
Group III		++		++										
			++	++		++								
				++		++		++						
									++					
									++					
									++					
										++	++	++		

mal thoracic vertebrae. The rib fusions were: (a) medial, (b) dorsal, to form a common element for vertebral attachment, or (c) ventral, to form a common element which inserted at the sternum. These lesions were unilaterally expressed with three on the right and one on the left. Six animals showed abnormal rib insertion.

More than half of the sterna were abnormal (Table 1). The abnormalities recorded for the sterna did not involve simple fusions such as those which are sometimes observed in normal stocks (Morgan 1954). In seven of the ten abnormals the sternebrae were irregularly shaped, the other three abnormals involved complex fusions and bifurcated xiphisterna.

Four mice had only six cervicals, thus indicating fusion of two vertebrae. Eleven mice had seven cervicals. Ce-3 through Ce-7 were characterized by particularly thin dorsal bridges.

Group II

Only one of the fifteen skeletons from this group had more than four caudal vertebrae which could be separately identified. The same general pattern of abnormalities was found here as in Group I. Approximately half of the sacrals, but none of the lumbars, were abnormal. Table 2 illustrates the affected areas for the thoracic vertebrae and table 3 for the ribs. In addition to the rib fusions there was one animal with medial disjunction of the dorsal and ventral halves of left R-2. Three mice with abnormal ribs also had abnormal thoracic vertebrae. Five of the 15 mice had abnormal rib insertion.

Nine sterna were abnormal. The same syndrome of abnormalities appeared here as in the group I animals. Six mice had only six cervical vertebrae; nine had seven. Two cases of dyssymphysis were observed: at T-1 and Ce-7. Thin dorsal bridges were again common in the cervical region.

Group III

A slightly different situation prevailed in respect to caudal vertebrae with this group of hybrids. Only 12 of the 32 mice had irregular vertebral fusions such that less than four separate vertebrae were recognizable. Seven animals had less than ten separated proximal caudal vertebrae and 12 had more than 20. As seen in table 1, the percentage of mice with abnormal sacral vertebrae here is comparable to that of groups I and II. In the lumbar region there were more abnormals than observed for the inbred sublines. However, the percentages were all below 10%.

Thoracic lesions were observed approximately half as often in this group as in the others. The incidence is given in table 1; the location of fusions in table 2. Eight abnormalities involved fusions and one involved irregularities only. In addition, one individual which appeared to be normal in the thoracic region had only 13 ribs and 13 thoracic vertebrae. Two mutants had 13 ribs on one side and 14 on the other.

Dyssymphysis was observed three times: once at T-13 and twice at T-1. Supernumerary cervical ribs were observed at Ce-7; four times bilaterally and three times unilaterally.

Figure 1 illustrates the extreme rib abnormalities observed in three specimens. Male No. 2726 lacked contact of R-8, 9, 10, 11, and 12 (right side) and R-11, 12, 13 (left side) with the thoracic vertebrae. In addition to this, T-10, 11, 12, and 13 were deformed, with T-13 having incomplete dorsal fusion.

Male No. 2548 had skeletal deformities throughout the vertebral column. As seen in figure 1B, R-11, 12 and 13 on the left side were not continuous in the area distal to the rib-neck. This condition was suggestive of a more severe expression of the

rib lesions in male No. 2726. Additional abnormalities of No. 2548 were: right R-4 fused to R-5 and R-6 fused to R-7, T-9 fused to T-10 and T-11 fused to T-12, Ce-4 fused to Ce-5 and xiphisternum attached proximally to the last sternebra at an angle.

The third individual to be described is male No. 2716. The abnormality illustrated here (fig. 1C) was observed occasionally in Tail-short mutants but usually two, rather than three, ribs were involved (Table 3). In addition to this abnormal rib fusion No. 2716 was abnormal as follows: T-5, 6 and 7 were fused, T-9, 10, 11, and 12 were fused (with spina bifida of T-12), the two halves of T-1 were not fused dorsally, L-4 was fused to L-5, Ce-1 was fused to Ce-2, the sternebrae were irregularly shaped and Ce-3, 4 and 5 were fused.

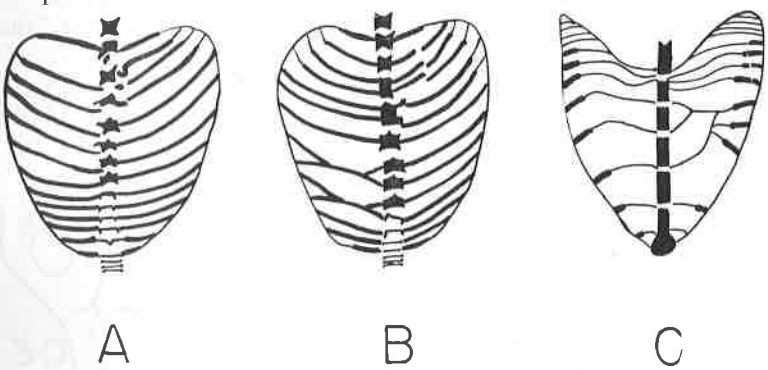


Fig. 1. Abnormalities of the thoracic basket.
A. Male No. 2726, dorsal view
B. Male No. 2548, dorsal view
C. Male No. 2716, ventral view

These three mutants are cited as extreme abnormals which demonstrate noteworthy lesions. Irregularities of the caudal and sacral regions were too numerous to list.

A final abnormality which was first observed in group III was concerned with the skull. The frontals of many specimens were separated not only topographically by a suture, but also by a space (fig. 2B). In other specimens a diamond-shaped bone was identified medially between the frontals and nasals (fig. 2C). Ultimately one or both of these lesions were recorded for 21 mice in group III; only three appeared to be normal in the frontal area. Five skulls saved from groups I and II were abnormal at the interfrontal suture.

Controls

The 18 normal-tailed controls were recorded as having the following counts of normal appearing skeletal structures: 30 or 31 caudal, 4 sacral, 6 lumbar, 13 thoracic and 7 cervical vertebrae. In addition to this, they all had 13 pairs of ribs, normal sterna and normal skulls.

Discussion

The data establish that there are additional morphological effects of the dominant mutation Tail-short. In addition to the pronounced tail shortening and body shortening which was previously described (Morgan, 1950), hidden anterior skeletal defects have been discovered. This primary action affecting both ends of the body is not unique to Tail-short, as it has also been observed in studies of stub (Dunn & Gluecksohn-Schoenheimer, 1942) and undulated (Grueneberg, 1950).

The phenomenon of dyssymphysis has been described for vertebrae Ce-1 and Ce-2 by Grueneberg (1950). He discussed the anomalies in terms of a threshold concept, which indeed seems plausible. When strain C57Blk, for which "dyssymphysis of atlas and axis is characteristic," was crossed with strain A "the

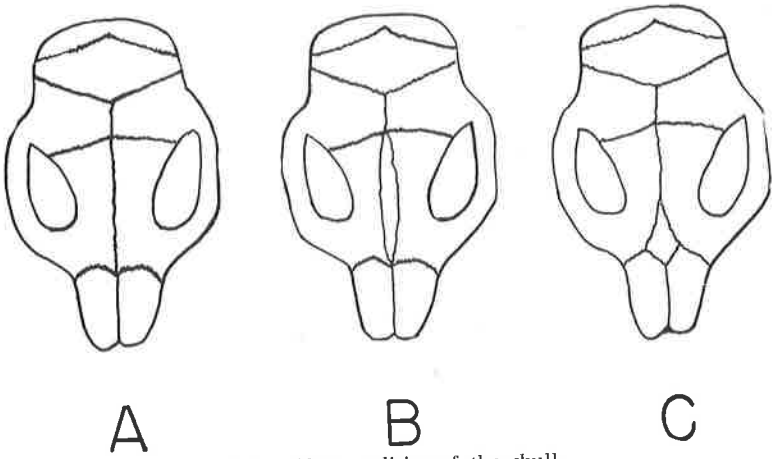


Fig. 2. Abnormalities of the skull.
A. Normal
B. Interfrontal space
C. Diamond-shaped interfrontal bone

character behaved as a recessive due to two or three pairs of genes." In the present study dyssymphysis was observed in ten of the 65 observed mutants as follows: Ce-3 (1), Ce-4 (2), Ce-7 (1), T-1 (5) and T-13 (1). The fact that six of these were from group III indicates that a dominant influence is transmitted with *Ts*. Grueneberg (1950) observed in studies of dyssymphysis, with hybrids from two of the strains in his laboratory, that "in a cross of C57 Blk with CK, the character behaved like a monogenic dominant."

Although weights were not recorded it was observed that Tail-short mutants grew more slowly than did their normal-tailed littermates. In many cases a later age at maturity and

reduced fertility accompanied this condition. Consequently, it was not surprising to find that a general retardation of skeletal components might be manifested as a part of the syndrome.

Keeler (1930, 1933) reported that interfrontals and parted frontals had been observed in two of his stocks. The anomalies observed in Tail-short mutants differed from those of Keeler's by intergrading into a continuum. That is, some of the skulls

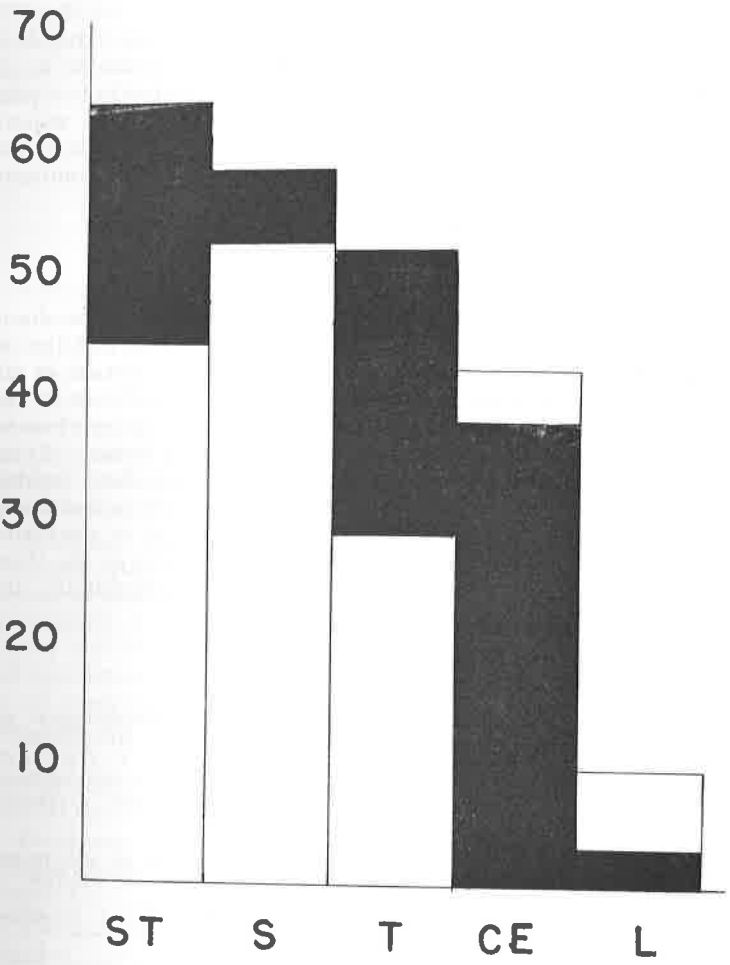


Fig. 3. Comparison of abnormalities in group III with groups I and II.
vertical axis = % of total with abnormalities
horizontal axis = affected region
● = average of group I plus group II
□ = Group III

had diamond-shaped interfrontals between the nasals, some had parted frontals (which could extend from the parietals to the nasals) and some had both. Cartilaginous structures are also deformed by the action of *Ts*, as illustrated in figure 1C. The costal cartilages of the true ribs showed occasional malformations.

The abnormalities of groups I and II have been combined to compare with group III. This method of comparison seems justified on the basis of genotypes because strain "C" was derived from the Bagg albinos. Inasmuch as abnormalities of the thoracic ribs and thoracic vertebrae were often related, these data were combined when computing the incidences for column T, in figure 3. The results shown in figure 3 demonstrate a phenomenon which is widely experienced in hybridization experiments—the presence of dominant modifiers which reduce the degree of abnormalities of mutants. This effect of dominant modifiers was also apparent in the caudal region.

Summary

Studies of alizarin red specimens have shown that the dominant mutation Tail-short produced presacral abnormalities in 58 of the 65 skeletons and post-lumbar abnormalities in all specimens. In addition to the longitudinal compression of the body the following phenomena were observed: (1) interfrontal lesions of the skull, (2) deformities of individual bones, (3) supernumerary cervical ribs, (4) rib fusions, (5) vertebral fusions, (6) abnormal sternebrae and (7) abnormal rib attachment. When the inbred Tail-short stock was outcrossed to unrelated stocks, the incidence of abnormalities was decreased in the three areas which showed 50% or more abnormal individuals: the sternum, the sacrum and the thorax.

Literature Cited

Carter, T. C. 1951. The genetics of luxate mice. I. Morphological abnormalities of heterozygotes and homozygotes. *J. Genet.*, 50: 277-299.

Dunn, L. C. and S. Gluecksohn-Schoenheimer. 1942. Stub, a new mutation in the mouse with marked effects on the spinal column. *J. Hered.*, 33: 235-239.

Grueneberg, H. 1950. Genetical studies on the skeleton of the mouse. I. Minor variations of the vertebral column. *J. Genet.*, 50: 142-173.

Keeler, C. E. 1930. "Parted parietals" in mice. A dominant hereditary character of the house mouse, *Mus musculus*. *J. Hered.*, 21: 19-20.
1933. Interfrontal—a heritable cranial variation of the house mouse. *J. Mammal.*, 14: 75-76.

Morgan, W. C. 1950. A new Tail-short mutation in the mouse. *J. Hered.*, 41: 208-215.
1954. A new Crooked tail mutation involving distinctive pleiotropism. *J. Genet.* 52: 354-373.