CROOKED NECK: AN INHERITED CONDITION IN JAPANESE QUAIL

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ABSTRACT

CROOKED NECK: AN INHERITED
CONDITION IN JAPANESE QUAIL

By

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A crooked neck condition that appeared six to seven days post-hatch was observed in highly significant numbers from one inbred line of Japanese quail at Michigan State University. In 93 percent of the cases, the neck was twisted to the right and the defect appeared in both sexes.

The severity of the defect seemingly did not increase with age. Some adult crooked neck birds were able to mate, although with considerable difficulty, and did produce viable offspring.

In general, out-crossing did not tend to lower the incidence of this condition. Although selection against the trait was practiced by removing afflicted individuals from the effective population, a sporadic incidence at a very low rate was observed in all lines. The crooked neck condition appears to be inherited, and the hereditary factors responsible for the condition were probably present in the base population. Eventhough the available evidence rather strongly suggests that the crooked neck condition

is inherited, the actual mode of inheritance was not determined.

When compared to normal siblings, three week and seven week male body weights, fertility, hatchability, and egg production were not affected by this condition.

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A THESIS

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to my wife

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INTRODUCTION

While weighing three-week-old Japanese quail (*Coturnix coturnix japonica*) from the pedigreed population maintained at Michigan State University, several birds with severely crooked necks were noted. In subsequent hatches, crooked neck progeny were also observed. Since the abnormal birds were from pedigreed stocks, common ancestors, if any, could be indentified. A lineage trace indicated that all the birds with the crooked necks had originated from the same parental line; thus further investigation of the condition was deemed desirable. This study was undertaken in an attempt to determine the mode of inheritance of the crooked neck condition in Japanese quail.

REVIEW OF LITERATURE

A review of literature revealed very few instances of fowl and quail afflicted with a crooked neck condition. Of those reported, only one was not lethal in effect.

A crooked neck dwarf lethal was first observed in the New Hampshire breed of chickens (Asmundson, 1945). Affected embryos possessed a short upper beak, a crooked neck, and a reduced sternum. The keel and lateral process of the sternum was absent, and the pectoral and leg muscles were greatly reduced in size. Bone hardness appeared to be unaffected. Most of the embryos that were examined at 22 days of incubation were dead. In a majority of those studied, the yolk sacs had been completely absorbed into the body cavity, which indicated the embryos had died after 19 days of incubation. Live embryos appeared to be rigid and unable to flex the hock joints. Afflicted embryos were never reported to have hatched.

The defect had no apparent effect on early embryonic mortality, but an increase in the percentage of dead in-shell and a reduction in hatch were observed. Analysis of off-spring ratios indicated that the abnormality was caused by simple recessive gene action.

Pun (1954) studied the crooked neck dwarf lethal in New Hampshires more extensively. In addition to the characteristics reported by Asmundson (1945), severe edema after the 11th day of incubation was noted. Edema was observed in ten percent of the embryos, and hydration in a majority of the remainder. Embryonic growth was markedly retarded after the 13th day of incubation. Loss of in-shell movement was noticed and was attributed to the extreme rigidity of the hocks and neck. Affected embryos never hatched, and peak mortality occurred between 20 and 21 days of incubation. Pun (1954) also reported the lethal embryo to have a crooked spinal column and curled toes. The toe condition was evident as early as ten days of incubation and was a useful criteria to identify the lethal embryos from normal ones.

Internal examination of crooked neck embryos showed the major organs to be reduced in size. The proventriculus and gizzard were empty while those in normal embryos contained digested matter. Esophageal atresia, which prevented the embryo from swallowing amniontic fluid, was evident. Pun (1954) suggested the lethal embryos died from chronic starvation. Further investigation into this area showed starvation to be a major factor contributing to the crooked neck dwarf lethal syndrome.

Crooked neck dwarf lethals resembling those found in the domestic fowl were reported in Broad Breasted turkeys

(Asmundson and Pun, 1956). A majority of the lethal embryos survived to 26 days of incubation. None were ever reported to have hatched. Retarded growth was noticed at approximately 12 days of incubation. Crooked-neck embryos could be identified from normal ones before esophageal atresia could cause starvation. However, it was concluded that starvation was a significant factor in the development of the lethal condition. As in chickens, the condition was attributed to simple autosomal recessive gene action.

Sittmann and Craig (1964), reported a crooked neck dwarf lethal condition in Japanese quail, Coturnix coturnix japonica. The necks of the afflicted embryos were twisted, and in most cases were twisted to the right. In-shell embryo position was also affected. When examined at 17 days of incubation, the head of the embryo was often positioned over, instead of under the wing. Crooked-neck embryos possessed slightly shortened upper beaks, and the legs crossed at the tibiotarsal joints, which were rigid. Unlike the characteristic toe condition reported in New Hampshires by Asmundson (1945), the phalanges in abnormal embryos were spread, and often in one plane. A reduced sternum and the absence of the lateral process were not observed in the Japanese quail. Skeletal structure of the quail mutants also appeared to be normal, rather than crooked, as reported in chickens.

The greatest mortality occurred between 14 and 18 days of incubation, and lethal embryos never pipped into the air cell. Sittmann and Craig (1965) suggested that the rigidity of the neck and legs hindered the normal hatching process. In contrast to the condition seen in crooked neck chickens and turkeys, digested matter was found in the digestive tract. Reduction of body size was also proportionally less in Japanese quail. Ratios in offspring from pedigree matings indicated the abnormality was a result of simple autosomal recessive inheritance.

Jull and Quinn (1931) reported a non-lethal crooked neck condition in Brown Leghorns. The condition was not evident at hatching but appeared when the fowl were about half grown. In most cases, the necks were twisted to the right, and no dwarfism was associated with the defect.

The abnormality was observed in both sexes. The crookedness of the neck was so severe that males could not mate, and adult females rarely laid eggs. It was also observed that as the birds aged, the condition became increasingly severe. Examination of several necks revealed little information, but Jull and Quinn (1931) suggested the condition was probably due to cessation in the growth of, or the misplacement of, one or more ligaments in the vertebrae. From offspring ratios obtained from "carrier" matings, the condition was found to be caused by simple recessive gene action.

Similar lethal conditions have been reported in Holstein-Friesan calves (Hutt, 1934) and in lambs (Roberts, 1929). Both conditions were attributed to autosomal recessive gene action.

One of the most studied mutations in mice is the Brachyury tail mutant (Dobrovolskaia-Zaradskaia, 1927). The condition is a dominant non-lethal that in the heterozygous state inhibits the normal development of the caudal axis, causing bending and shortening of the tail.

Wittman and Hamburg (1968) investigated developmental changes of the tail and found three major factors to be responsible for the blunting and twisting. Shortening of the tail was determined to be from reduction in the number of caudal vertebrae, while fragmentation and fusion of vertebrae was most likely responsible for the twisted appearance.

Expressivity and penetrance of the Brachyury condition was tested by outcrossing into four different and known genetic backgrounds. With the DBA strain; expressivity was modified when the DBA background was provided by the female parent. In the reciprocal cross, the expressivity remained unchanged. Green (1936) reported a similar phenomena. However, the penetrance was modified to a 2:1 ratio from the 1:1 expected ratio in both reciprocal crosses. The authors suggested that the shift toward a normal tail condition was probably a result of modifier action that tended to correct the faulty mechanism, thus restoring caudal vertabrae. They further suggested that expressivity modifiers were probably non-nuclear in origin, while factors effecting penetrance most likely had a more orthodox nuclear genetic loci.

According to Lerner (1954), after the rediscovery of the Medelian laws and their modifications, the interpretations placed on the detrimental effects of inbreeding were usually put on specific genes possessed by the inbreds, rather than the "mystical" powers of inbreeding itself. When monsters, lethals, and other defects are encountered after continuous consanguineous matings, it is automatically assumed that recessive genes were present in the initial population. Inbreeding allowed the expressivity by increasing the probability of homogygotes. However, heritable complexes and defect syndromes have been also found, with or without inbreeding, whose occurrence could not be made to fit simple or modified Mendelian ratios. Some authors have suggested that the inheritance of these complexes and syndromes are most likely due to multiple gene action with penetrance variation and threshold mechanisms of expression. Lerner (1954) does not totally reject this explanation, but states that in natural populations outside the laboratory the appearance is connected with balancing mechanisms in Mendelian populations based on a favored heterozygote, and thus, related to the phenomena of what he terms inbreeding degeneration. As an example of a phenodeviant of this type, Lerner discussed the condition of crooked toes in the domestic fowl.

In most closed populations of domestic fowls, hatching chicks with slight flexings of one or more toes are commonly seen. Lerner selected for this condition, and after thirteen years produced a line breeding pure for crooked toes. At the time of 100 percent incidence and severity, the amount of inbreeding was approximately 40 percent.

Intense reverse selection was also practiced but did not eliminate the defect in the back selected lines, even though the inbreeding coefficient reached 60 percent.

A loss in reproductive fitness was seen as the lines became more homozygous, but, remarkable enough, it improved after a 100 percent incidence of crooked toes was attained. However, the reproductive ability of the reverse selection lines decreased markedly, and was almost lost. A positive correlation between the level of inbreeding and the incidence of crooked toes was also found.

Crosses between lines of different incidences and into control stocks produced results that would require liberal assumptions regarding penetrance and expressivity to make them fit the results expected in a Mendelian scheme. Even though multigenic inheritance could not be ruled out, Lerner (1954) concluded that general inbreeding degeneration was the motivating action for crooked toes.

OBJECTIVES

1. To determine the mode of inheritance of the crooked neck condition.
2. To determine the effect of this condition on the following traits.
    a. Fertility
    b. Hatchability
    c. Embryonic mortality
    d. 3-week body weights
    e. 7-week body weights
    f. Egg production

DESCRIPTION

The crooked neck condition observed in Japanese quail at Michigan State University was not apparent at the time of hatching. Affected birds did not deviate phenotypically from normal ones until six to seven days after hatching. In 93 percent of the cases, the neck was twisted to the right, and the defect appeared in both sexes. Expressivity was variable, ranging from very mild to extremely severe (Figure 1).

Phenotypically, this condition more closely resembled the affliction described in Brown Leghorns by Jull and Quinn (1931) than that cr those reported in New Hampshires by Asmundson (1945), in turkeys in Asmundson and Pun (1956), and in Japanese quail by Sittmann and Craig (1965). Unlike the non-lethal condition reported in Brown Leghorns by Jull and Quinn (1931), the severity of the defect in the quail, seemingly, did not increase the age. In some cases, birds noted as having the crooked neck condition at six to seven days of age appeared to be normal the time of sexual maturity. However, in a majority of these instances, the birds had been classified as only mildly afflicted.

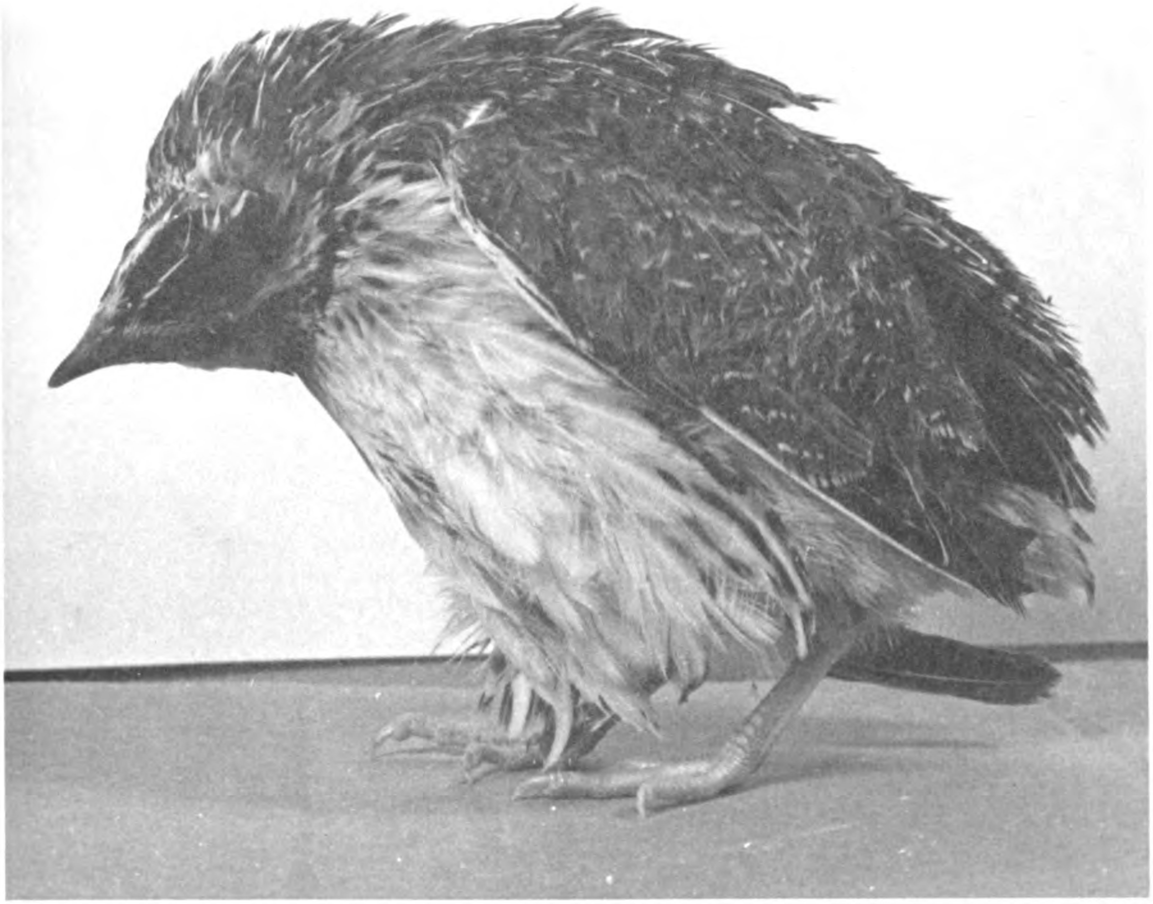

FIGURE 1.--Adult crooked-neck Japanese quail.

Some adult crooked neck birds were able to mate, although with considerable difficulty, and did produce viable offspring.

EXPERIMENTAL PROCEDURE

Population

Five inbred lines were utilized in this study. The term "line" as used herein defined as all birds that were derived from an original parental pair by consecutive brother x sister matings and had an inbreeding coefficient greater than 50 percent. However, the classical form of inbreeding was not followed. In most cases, more than one brother x sister mating was made per line for each generation, thus forming several "sub-lines" within the original line.

The Japanese quail used to produce the inbred lines were those from the Michigan State University Poultry Science Department's experimental farm that had been maintained for at least 10 years and had been under a closed flock mating system for a minimum of 25 generations.

In an attempt to maintain the inbred lines, all the offspring within a given line or sub-line from the last full brother x sister mating had been mass mated, shortly before the crooked neck condition was first noted. Of the five lines thus maintained, numbers of crooked neck progeny were obtained in significant numbers ($p<.01$ $X^2=8.83$)

from only one line. Within this line, three sub-lines (96, 32, and 24) existed with four, three and two families per sub-line, respectively.

The term "family" is herein used to designate full-sib mass matings within sub-lines and mass matings among the subsequent offspring. Only phenotypically "normal" birds were used in the effective population, and no overt selection was practiced for any production traits. Only offspring from within a particular family were mated together to preserve family, sub-line, and line purity.

When the abnormal birds were first noted in the population, the nearest relatives available for pedigree matings were from the mass matings previously described. Fortunately, the mutants were seen in the first generation that had been produced by the mass matings, and thus, the parents still had a full-sib relationship. Enough birds were removed from the parental mass matings to make twenty-five full-sib and out-cross pair matings. However, by this time, the parental birds were very old and many died or were not sexually active, and, consequently, offspring were secured from only six of these matings. (Table 3).

A random mating population served as the controls in this study. At the time of the investigation, the control stock had been maintained as a closed population for an estimated twenty-five generations.

Three types of mass matings of crooked neck x crooked neck individuals were made (Table 2). One of these matings involved only individuals within one sub-line. The second mating included crooked neck birds from sub-lines 96, 32, and 24. The third mating involved only sporadically occurring phenotypic crooked neck individuals from the remaining four inbred lines and the control population.

To prevent a possible carry-over of fertility, a two-week waiting period was allowed before eggs were saved for hatching purposes, after matings were made or changed.

Management Procedures

Adult birds with crooked necks were pair or mass mated in Petersime 2SD batteries. Matings in small cages could not be fully utilized because the severity of the neck condition would not allow the birds so housed to reach food and water. Pair matings that involved only phenotypically "normal" birds were made in 15cm x 15cm x 20 cm wire cages that had been especially designed for quail pedigree matings.

Cages were constructed in units of six and were suspended in the framework of a Jamesway C.B. 2371 battery brooder. Twenty of these units were installed in one Jamesway frame, which allowed 120 pedigree matings to be conducted at the same time in the same place. Modified Jamesway C.B. 2371 battery brooders were used to maintain the mass matings of "normal" inbreds and the control population.

Single pair pedigree matings were conducted in a 3m x 5m windowless light controlled pen, and battery matings were made in batteries located in a 12.5m x 18.1m windowless room. In both cases, air movement was regulated by thermostatically controlled fans. Lighting was provided twenty-four hours a day by 100 watt incandescent bulbs. Food and water were provided _ad libitum_. Composition of the breeder ration is shown in Appendix A.

Eggs were gathered daily, pedigreed by pen/cage and date, and stored for up to one week in an egg holding room at the research farm. The eggs were fumigated and brought to the incubation facilities once a week for setting. Eggs were then sorted by pen or cage number, and placed small end down in wire mesh baskets that were designed to fit the tray cradles. Eggs were set weekly in Jamesway 252 single stage incubators. Setting units were maintained at 37.9°C with a relative humidity of about 60 percent. Egg turning was done automatically every two hours. After 14 days of incubation, the eggs were transferred into pedigree hatching baskets and put into a hatching unit which was maintained at 36.5°C with a relative humidity of about 70 percent.

Quail chicks were removed and wing banded twice daily starting with the 17th day of incubation, and eggs that did not hatch were broken out on the 19th day of incubation to determine fertility and embryonic mortality.

Embryonic mortality was classified into four categories: early dead; middle dead; late dead; and pips.

Early deads included all eggs that showed any degree of celluar organization to the formation of the eyes of the embryos. This period was from approximately one to three days of incubation. Embryos that exhibited any eye development through the absorption of the yolk sac into the body cavity were placed into the middle dead category. This classification period approximated four to fifteen days of incubation.

Late deads included those embryos that had absorbed the yolk sac into the body but had not yet broken into the air cell. Embryos that had broken any part of the shell but had failed to hatch were called pips. Pips that were alive at 19 days of incubation were not helped out of the shell.

Chicks were brooded in Petersime 2SD batteries that had been manufactured especially for quail. Each of the six decks had a thermostatically controlled heating element, and each deck was divided into two 68.6cm x 102.6cm compartments. Brooding temperatures were set at 38°C for the first week, then lowered 5°F a week for three weeks. One-quarter inch wire mesh floors were also used for the first three weeks to prevent serious leg injuries. Lighting was provided on a 24 hour basis for at least one week, then on a regime of 15 1/2 hours of light per day. Special trough feeders were used, and were placed in a position that would overlap the heated and unheated part of the pen. Regular size chick jar waters were used to provide water. Marbles or perforated plastic rings in the bases were used to minimize drowning losses. At three weeks of age, quail were transferred to compartments with one-half inch mesh floor wire and standard size trough waterers and feeders.

All birds within a particular hatch were reared together until 5 1/2 to 6 weeks of age. At this time, birds were sexed by plumage color and males and females separated. Then, the birds were transported from the growing facilities to the experimental farm for mating and housing. The birds were generally not more than 8 weeks of age at the time of mating.

DATA COLLECTION AND ANALYSIS

Egg production was recorded for all females used in this study. Production records were transformed into the more conventional hen-housed production on a per week basis. For the mass matings, calculations were based on the total number of females initially housed vs the egg production for a seven day period. For pair matings, the total number of eggs produced in the seven day period was used. Soft-shell eggs were excluded from the final analysis. The seven day collection period was from Friday through Thursday of each week.

Fertility was measured as the percent age of all eggs set from any given mating that hatched plus unhatched eggs that showed any degree of cellular organization or embryonic development. Development was judged by macroscopic examination of the interior content of the egg.

Hatchability figures were derived by the total number of eggs that hatched divided by the total number of fertile eggs.

Individual body weights to the nearest gram were taken at three and seven weeks of age. The three-weeks-of-age period was chosen for measurement because it was representative of a time of growth that was not under the influence of sex hormones or egg size. Body weights were examined at seven weeks of age for convenience rather than for any specific reason. At this time, birds were being handled for transfer to holding pens prior to mating. At the time of weighing, birds were also examined for signs of sexual maturity.

To eliminate, environmental effects, data were analyzed by the paired data analysis method. Data used as a comparison to the crooked neck individuals or eggs from crooked neck male x crooked neck female matings were collected only from individuals or eggs that were contemporary with the crooked neck bird data, and were from phenotypically normal siblings to the crooked-neck birds.

Prior to analysis, all percentage data were changed to twice the arcsin of their square roots and all Chi square analysis included Yates correction for continuity.

RESULTS AND DISCUSSION

Data on the incidence of crooked neck offspring from the nine families which produced a significant number of progeny that exhibited this condition are presented in Table 1. The data were collected over a period of one to three generations per family and were from a total of 15 mass matings. Incidence varied from family to family within and between sub-lines. Even though some difference occurred within certain families between generations, total sub-line incidence remained fairly uniform. Families from sub-line 32 showed higher incidences than families in sub-lines 96 and 24.

Results of crooked neck x crooked neck mass matings are presented in Table 2. Of all mass matings made, that of individuals within a sub-line produced the highest incidence of crooked neck offspring. Mass mating crooked neck birds from different sub-lines produced an incidence intermediate to the incidence from the within sub-line mating (mating 1) and the incidence from a mass mating of phenotypically "normals" from the between sub-line cross (mating 2). The mass mating (mating 3) of sporadically occurring phenotypic crooked neck individuals from the

TABLE 1.--Incidence of crooked neck offspring from mass matings.

Sub-line	Family	Generations of inbreeding	Generation 1			Generation 2			Generation 3		
			Total offspring	Crooked neck offspring		Total offspring	Crooked neck offspring		Total offspring	Crooked neck offspring	
			No.	No.	%	No.	No.	%	No.	No.	%
96	A	5	91	7	7.7	78	7	9.0	80	7	8.7
96	B	6	30	1	3.3	37	3	8.1			
96	C	6	12	1	8.3						
96	D	6	75	3	4.0						
32	E	4	17	2	11.8						
32	F	5	40	6	15.0	31	1	3.2	80	11	13.7
32	G	5	27	5	18.5	33	8	24.0			
24	H	6	99	8	8.1						
24	I	7	10	1	10.0						
Control		0	317	2	0.7						

TABLE 2.--Crooked neck x crooked neck mass matings.

No. of mating	Description	Total offspring	No. with crooked neck	%
1.	Within sub-line 96 (Families A, B, C, D)	10	3	30.0
2.	Within and/or between sub-lines (Families A through I)	15	3	20.0
2a.	F_1 x F_1 Normals of mating 2	27	3	10.4
3.	Non-related lines[1]	44	3	6.8
4.	Control	115	0	0.0

[1]Mass mating of sporadically occurring phenotypic crooked neck individuals from four inbred lines and controls.

four other inbred lines and control stock produced the lowest incidence of crooked neck progeny.

Data on the incidence of crooked neck offspring from full-sibling and outcross matings are given in Table 3. With only one exception, outcross matings, whether one or none of the parents were afflicted, produced no crooked neck offspring in the first generation. However, all F_1 normal x normal matings produced some crooked neck individuals. Matings which included individuals from sub-line 32 produced crooked neck progeny at a higher incidence than did the other matings. A mating again crossing sub-lines (Family G x Family A) produced an incidence intermediate to crosses that utilized a parent or parents from sub-lines 32 or 96.

Egg production, fertility, hatchability, and embryonic mortality data are given in Table 4. Hen-housed egg production for phenotypically crooked-neck females averaged 73 percent, as compared to 73 percent for contemporary normal siblings. Fertility and hatchability from crooked neck male x crooked neck female matings proved to be non-significantly different ($p<.05$) from that of phenotypical normal siblings. However, significant differnces ($p<.01$) were observed in two of the various categories included in embryonic mortality.

TABLE 3.--Full-sibling and outcross matings.

	No. of matings	Total offspring	No. with crooked neck	%
Family D normal ♂ x Control normal ♀	1	25	0	0.0
F_1 normal ♂ x F_1 normal ♀	1	20	2	10.0
Family D crooked neck ♂ x Control normal ♀	1	16	0	0.0
F_1 normal ♂ x F_1 normal ♀	2	23	1	4.4
Family F normal ♂ x control normal ♀	1	9	0	0.0
F_1 normal ♂ x F_1 normal ♀	2	23	7	30.4
Family A Normal ♂ x Family A normal ♀ (full-sibs)	2	44	5	11.4
Family G crooked neck ♂ x Family A normal ♀	1	16	3	19.0
Control normal ♂ x Control normal ♀	43	230	1	0.44

TABLE 4.--Egg production, fertility, hatchability and embryonic mortality data.

		Number[1]	Crooked-neck x Crooked-neck %	Normal %	S.E.[2]
I.	Egg production	17	72.7	73.1	.005
II.	Fertility	12	86	80	.22
III.	Hatchability	12	59	60	.22
IV.	Embryonic mortality				
	Early dead	11	14	13	.09
	Middle dead	11	22**	13	.06
	Late dead	11	00	11**	.05
	Pip	11	5	3	.01

[1]number of paired observations.

[2]standard error.

**p<.01.

The percentage of early deads from the crooked-neck bird matings averaged 14 percent while 13 percent early deads were observed in normal sibling matings. These percentages were not significantly different. When compared to normal siblings, about twice as many middle deads were observed from the crooked-neck male x crooked-neck female matings--a highly significant difference ($p<.01$). Careful examination of the middle deads from the crooked-neck matings did not reveal any of the abnormal characteristics described by Sittmann and Craig (1965) nor esophageal atresia noted by Pun (1954).

If this condition were similar to that seen by Sittmann and Craig (1965) peak mortality would have occurred at approximately 15 days of incubation or, corresponding to the late dead category. From the three matings which included only birds with crooked necks no embryonic deaths were noted in the late dead classification (Table 4).

In general, three week and seven week body weights of crooked neck males were not different from those of their normal brothers. (Tables 5 and 6). However, when pooled, seven week body weights of crooked neck females were significantly different ($p<.05$) than those of their contemporary normal sisters (Table 7). A possible explanation for the difference is that the crooked neck females appeared to become sexually mature about a week later than their normal sisters. Development of the reproductive

TABLE 7.--Seven week body weights of crooked neck and "normal" female Japanese quail.

		Generation 1			Generation 2			Generation 3		
Sub-line	Family	number[1]	crooked neck gms.	normal gms.	number[1]	crooked neck gms.	normal gms.	number[1]	crooked neck gms.	normal gms.
96	C	1	103	112						
32	E	1	104	113						
32	G	---	---	---	2	112	112			

[1]number of paired observations.

tracts in the normal females could have accounted for the additional weight.

Of those offspring that survived six days post hatch from the normal mass matings, 9.6 percent exhibited the crooked neck condition, a significant deviation from the expected 3:1 ratio if this condition were due to a single pair of recessive genes. However, mortality for the first six days averaged 31.0 percent, thus leaving open the door that the condition might be a simple Mendelian semi-lethal. Data from crooked neck x crooked neck mass matings (Table 2) tended to refute this hypothesis. Instead of the 100% crooked neck offspring expected, only 12.5 percent of the progeny from these matings exhibited the condition. Consequently, if the condition was due to a single pair of recessive genes, penetrance was obviously extremely low. But, if penetrance was responsible for the low expressivity of the condition, the number of affected offspring from all crooked neck x crooked neck matings should be the same. Again, data from crooked neck x crooked neck mass matings (Table 2) tended to disprove this theory. The incidence of crooked neck progeny within sub-line 96 crooked neck x crooked neck mass mating was 30 percent while the occurrence of crooked neck offspring from non-related crooked neck parents was only 6.8 percent. Thus, the differences in offspring ratios from crooked neck x crooked neck matings was most likely not due to penetrance.

Data from the full-sibling and outcross matings (Table 3) did not shed any additional light on the mode of inheritance. The possibility that the condition may have a multi-genic basis cannot be ruled out, and may be the best explanation of inheritance. However, neither can the possibility that inbreeding degeneration was involved (Lerner, 1954), or a combination of multi-genic inheritance and inbreeding degeneration.

The differences in percentages of crooked neck offspring observed from the various family mass matings (Table 1) and crooked neck x crooked neck mass matings (Table 2) might have been due to a possible difference in the degree of homozygosity associated with each sub-line. Although sub-lines 96, 32, and 24 originated from the same parental pair, relationship coefficients between sub-lines at the time of this investigation were less than 0.30. On the other hand, coefficients of relationships within sub-line families were greater than 0.625.

The families in sub-line 32 (families E, F and G) and their respective test matings produced crooked neck offspring at a higher percentage than did any other combination (Tables 1, 2, and 3). Possibly, these families were more homozygous for the factors that allow expressivity of this defect than were the other families.

The low incidence of crooked neck birds in the control population was most likely from chance matings of individuals carrying the gene(s) for the crooked neck condition.

SUMMARY AND CONCLUSIONS

A crooked neck condition that appeared six to seven days post-hatch was observed in highly significant numbers from one inbred line of Japanese quail at Michigan State University. In 93 percent of the cases, the neck was twisted to the right and the defect appeared in both sexes.

The severity of the defect seemingly did not increase with age. Some adult crooked neck birds were able to mate, although with considerable difficulty, and did produce viable offspring.

In general, out-crossing did not tend to lower the incidence of this condition. Although selection against the trait was practiced by removing afflicted individuals from the effective population, a sporadic incidence at a very low rate was observed in all lines. The crooked neck condition appears to be inherited, and the hereditary factors responsible for the condition were probably present in the base population. Eventhough the available evidence rather strongly suggests that the crooked neck condition is inherited, the actual mode of inheritance was not determined.

When compared to normal siblings, three week and seven week male body weights, fertility, hatchability, and egg production were not affected by this condition.

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APPENDIX A

TABLE 1.--Composition of quail ration.

Ingredients	Percent of ration
Ground yellow corn	41.25
Soybean oil meal, 50%	37.00
Alfalfa meal, 17%	5.00
Dried whey	2.50
Meat and bone scraps, 50%	2.50
Fish meal, Menhaden, 60%	2.50
Dicalcium phosphate	1.50
Ground limestone	5.00
Salt, iodized	0.50
Vitamin, premix*	0.25
Fat	2.00

*NOPCOSOL M-4, Nopco Chemical Company, Harrison, New Jersey.