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Developmental Malformations in *Avian* Species. Manifestations of Unknown or Genetic Etiology-A Review

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ABSTRACT

The anomalies which occur during the development of the avian organisms result in structural and functional abnormalities. In the present review, the majority of surveyed reports on developmental malformations are related to wild birds and secondarily to poultry birds. Regarding their etiology, spontaneous and genetic aberrations were surveyed. The great part of malformations refers to the skeletal system. Among them, the most frequently occurring types were beak deformities, absent, supernumerary or deformed limbs. Embryonic conjoined duplications were also recorded. Anomalies of structure, number and coloration of feather were highlighted. Abnormalities of the heart and ocular malformations were compiled. Also, malformations of the gastrointestinal as well as of the uro-genital system were collected. The malformations which were briefly described constitute a database which could be a useful tool for the further study of embryology, experimental toxicology and teratology of animals.

INTRODUCTION

The birds represent a big part of animal diversity. They constitute a section of the wild fauna, are used for meat and egg production and also as pet animals. Additionally, many of them are utilized as experimental animals. During the development of an avian organism appear malformations which mainly occur during the pre-hatching period as well as during the post hatching period. Hence, developmental malformations are defined as abnormalities of structure and many times of position present at hatching (congenital malformations or congenital deformities-anomalies). Most defects are recognized at hatching but some go undetected until somewhat later.

The causes of congenital malformations can be divided into 3 categories: unknown, genetic and environmental. The cause of a majority of animal malformations is unknown. A significant proportion of congenital malformations of unknown cause is likely to have an important genetic component.

The knowledge of normal and abnormal development of avian organisms has intrigued the scientific community from the very old years. Romanoff (1972) published a classical textbook on the pathogenesis of the avian embryo. Through a few thousands of references the developmental procedures and abnormalities of the fowl and other poultry birds were analyzed. A review on the developmental disorders of the skeleton of domestic chickens and turkeys (Riddell, 1975) summarized in a great extend the skeletal malformations of these poultry species. Consequently, Crawford (1990) in his textbook "Poultry Breeding and Genetics" included many chapters dealing with the inherited abnormalities of avian species with special reference to species which are used

in animal production. The authors of the relevant chapters surveyed in extent as well as in depth the abnormalities in Domestic fowls, Geese, Turkeys, Japanese quails, Ring-necked pheaseants, Domestic ducks, Guinea fowls and Muscovy ducks. Additionally the authors focused mainly in abnormalities of genetic etiology. However, enough publications of spontaneous or experimental embryological-teratological nature were omitted. Since that time many more records have appeared in the literature and simultaneously many of them shifted towards the impact of Toxicology and environmental pollution on birds.

In the present review the literature survey will fill the gaps between the works of Romanoff and Crawford with the up to date bibliography on this subject. The aim of the survey is to provide a broad and thorough database of information regarding the major proportion of such malformations.

Early lethal conditions: Blood ring is an early embryonic lethal condition initially observed in fertilized Wrolstad Medium White turkey eggs after 10 days of incubation. The blood ring (*blr*) had a discernable embryo and a sinus terminalis (Savage and Mirosh, 1992). Another early embryonic lethal condition was observed in dwarf Single Comb White Leghorn chickens (Savage *et al*., 1992). The disorder called blastoderm degeneration is macroscopically evident at 32 h of incubation. Microscopically is characterized by a series of retarded developmental processes. The symbol *bld* was proposed for this recessive gene.

Conjoined twins: Twin avian embryos occur rarely. Two symmetrical double malformations with four legs and two anuses were described in a Sex-Sal chick (Hoffmann, 1968). The supernumerary shorter legs were located laterally to the normal legs and connected by connective tissue with the scapulae. Both anuses were functional. A conjoined twin mallard (*Anas platyrynchos*) has been reported during an experiment. The embryos were joined at the head and neck region (Batt *et al.,* 1975). The avian double monsters occur frequently in ducks where about 2% of all fertilized eggs form such malformations (Ulshafer and Clavert, 1979). The authors observed a great amount of duck eggs between 48 and 72 h of incubation and categorized the double monsters in four different groups. In Group 1 the notochords approached each other medially. The twins shared a common cephalic extremity, having one well formed prosencephalon with one set of optic rudiments and one or two hypophyses. In Group 2, the notochords approached each other medially. Each embryo had its own forebrain which had either both or only one lateral optic rudiment. In group 3 the notochords approached each other frontally. Both embryos lacked all forebrain structures. In some cases rhomboencephalic structures of both embryos were normal while frequently one or both twins lacked otic rudiments and/or hindbrain entirely. In Group 4, the secondary embryo approached the first somewhat perpendicularly. The primary embryo was normal while the twin lacked optic vesicles and frequently other brain structures. During a study of embryonic respiration in the Wedge-tailed shearwater (*Puffinus pacificus*), an egg was collected and found to contain a double conjoined twin embryo. The body of the embryo was completely duplicated except for a common head with one eye absent and the brain exposed on the left side (Pettit and Gousey Whittow, 1981). Malformed chick embryos encountered during experiments on embryos at the 2nd and 3rd day of incubation have been collected by Nakamura and Itasaki (1991). Among them, conjoined twins in which the two embryos shared a head and each embryo extended in opposite directions were observed. Also parallel twins with fused heart tubes were described. An Arbor Acres female X Peterson male crossbred 6 week-old female broiler chicken possessed four legs, two cloacae and three ceca (Ebako *et al*., 2002). The intestines occupied the caudo-dorsal portion of the abdominal

cavity with three ceca attached to the terminal end of the ileum. The left lateral cecum was larger and had a divided distal end that terminated into 2 cm-long blind sacs. The rectum was dilated and divided into two cloacae. The two extra legs were attached to the pygostyle. The extra legs were smaller in size compared with the normal legs.

A case of conjoined cephalopagus twinning in an ostrich (*Struthio camelus*) has been described by Mazzullo *et al.* (2007). The twins displayed one head containing a single brain, two spinal cords and deviated vertebral columns. Both twins possessed two upper and lower limbs each.

Beak deformities: Abnormal bills in wild birds are rare, with a frequency estimated at less than 0.5% (Pomeroy, 1962). Pomeroy reviewed the literature concerning species with abnormal bills and their probable causes. He listed the types of deformities as crossed mandibles upper mandible decurved, lower mandible upcurved, upper mandible upcurved and/or lower mandible decurved, elongation, lateral curvature and locked bills. Abnormalities of the beak are also seen in poultry species (Riddell, 1975). According to the majority of surveyed deformities a genetic basis was assigned. Bill deformities seem more prevalent in certain groups of passerines (Craves, 1994). According to the author the families Icteridae and Mimidae as well as species such as European starlings (*Sturnus vulgaris*) and House sparrows (*Passer domesticus*) present high incidence of reported deformities. Craves provided tables which summarized a considerable number of these reports. Table 1 summarizes some old reports which were omitted from previous publications as well as updated reports of beak malformations.

Short beak is a new semi-lethal mutation of Japanese quail (*Coturnix japonica*). The affected birds are characterized externally by short beaks, shanks and digits. Genetic analyses revealed that the short beak mutation is controlled by an autosomal recessive gene. The proposed gene symbol is *sbk* (Tsudzuki *et al.*, 1998).

Table 1: Beak malformations in avian species

Species	Malformation	Reference
Downy woodpecker (*Picoides pubescens*)	Upper mandible abnormal in shape	Whittle (1927)
American bittern (*Botaurus lentiginosus*)	Upper bill decurved and crossed	Batts (1954)
Common grackle (*Quiscalus quiscula*)	Crossed bill	Wetherbee (1958)
Mockingbird (*Mimus polyglottos*)	Upper bill undifferentiated	Wetherbee (1958)
Ruffed grouse (*Bonasa umbellus*)	Remarkable parallel growth of the three divisions of the upper bill	Stott (1970)
California gull (Larus californicus)	Decurved bill	Smith and Diem (1971)
Westen bluebird (*Sialia mexicana*)	Crossed bill	Eltzroth (1996)
Brewer's blackbird (*Euphagus cyanocephalus*)	Not defined	Eltzroth (1996)
American robin (*Turdus migratorius*)	Not defined	Eltzroth (1996)
Red-tailed hawk (*Buteo jamaicensis*)	Not defined	Eltzroth (1996)
American kestrel (*Falco sparverious*)	Not defined	Eltzroth (1996)
Osprey (*Pandion haliaetus*)	Not defined	Eltzroth (1996)
Lesser snow geese (*Chen caerulescens caerulescens*)	Reduction of both mandibles;lower mandible reduced and decurved;	Rockwell *et al.* (2003)
Brown-headed cowbird (*Molothrus ater*)	Reduced and crossed; abnormally long upper mandible; upper mandible recurved	Stewart (1963)
	Crossed bill	Rindoul (2005)

Feather: Much has been written about the structure, number and pigmentation of the feathers of birds. Bird plumage aberrations can be restricted to a single feather, a group of feathers or may concern the entire body which changes radically the appearance of an individual bird. The most striking anomalies in plumage are albinism resulting from the total lack of pigment production and leucism resulting from some other deficiency in the pigmentation process. Leucism is a form of incomplete partial albinism in which the eyes, bill and legs remain normally colored, while the plumage contains no color pigments or decreased pigmentation (Sage, 1962). Sage compiled 3134 records of albinism in British birds. The great bulk of records (67%) have occurred in the Turdidae, Corvidae, Hirundinidae, Passeridae, Sturnidae and Fringillidae. Gross (1965a) published two accounts on the incidence of albinism and melanism in North American birds. Regarding the albinism, Gross (1965a) classified albinos birds into four groups: 1. Total or pure, 2. Incomplete, 3. Imperfect, 4. Partial. Also, he listed 54 families in which albinism have occurred and found 304 albinistic species represented by 1847 individuals. Regarding melanism, Gross (1965b) noted only 29 species in which this abnormality occurred. In his paper referred also to two other types of color anomalies in feathers. He mentioned the erythrism (intensification of red pigment) and the xanthochroism (abnormal coloring of the plumage in which yellow color replaces the normal coloring). Table 2 summarizes color abnormalities of feather in various avian species.

A new mutation has been identified in the turkey that inhibits the rate of feathering (Zakrzewska and Savage, 1997). The abnormality affected the number, size and structure of feathers. At hatch the affected birds lacked flight feathers. As the birds grow, the expressivity of the disorder may vary. The symbol *K*IF* was proposed for the mutation. A case of an urban-breeding pair of northern goshawks (*Accipiter gentiles*) that produced five aberrant offspring with diluted plumage coloration and severe locomotory disorders has been published by Rutz *et al*. (2004).

Abnormalities in the number and structure of feathers have been frequently described involving many species. Stresemann (1963) published an account on the variation of primaries. He reviewed the available literature and examined 4 specimens with abnormal number of primaries. The

Table 2: Anomalies of feather coloration in avian species

Species	Anomalies	Reference
Mew gull (*Larus canus*)	Partial Albinism	Winter (1985)
Northern flicker (*Colaptes auratus*)	Melanism	Cringan *et al*. (2006)
Red-backed shrike (*Lanius collurio*)	Melanism	Ciach (2009)
European starling (*Sturnus vulgaris*)	Partial Albinism	Hicks (1934)
Brown-headed cowbird (*Molothrus ater*)	Partial Albinism	Stewart (1963)
Collared trogon (*Trogon collaris*)	Partial Xanthochroism	Eisenmann and Omland (2007)
Great tit (*Parus major*)	Albinism	Guesada (2006)
Yellow-faced grassqnit (*Tiaris olivacea*)	Partial melanism Xanthochroism	Smith (1966)
Cape May warbler (*Dendroica tigrina*)		
Evening grosbeak (Hesperiphona vespertina)	Xanthochroism	Godfrey (1967)
Evening grosbeak (Hesperiphona vespertina)	Xanthochroism	Helleiner (1979)
Purple finch (*Carpodacus purpureus*)	Xanthochroism	Isted (1985)
Osprey (*Pandion haliaetus*)	Melanism	Clark (1998)
Northern harrier (*Circus cyaneus*)	Melanism	Howell *et al*. (1992)
Pileated woodpecker (*Dryocopus pileatus*)	Melanism	Short (1965)
King penguin (*Aptenodytes patagonicus*)	Partial melanism	Blight and Stevens (2000)

specimens were a Horned screamer (*Anhima cornuta*), a Cassin's auklet (Ptychoramphus aleuticus), a Bar-tailed godwit (*Limosa lapponica baueri*) and a Glossy ibis (*Plegadis falcinellus*). In a thorough examination of 200 Saw-whet owls (*Aegolius acadica*), a bird was found to possess only 9 primaries whereas other birds had unequal number of restrices (Mueller and Berger, 1966). A case on the lack of feathers in a juvenile Brown noddy (*Anous stolidus*) has been recognized by Schreiber (1975). The complete absence of coverts and flight feathers characterized the individual. Down feathers appeared to be of normal length but were sparsely distributed.

A generalized feather abnormality (pinching off syndrome) has been described in various European birds (Bijlsma and van der Burg, 2006). The nestlings develop malformed remiges and/or restrices. Malformed feathers are often symmetrically positioned in wing and/or in tail. In the Netherlands this syndrome has been recorded in Northern goshawk (*Accipiter gentilis*), Common buzzard (*Buteo buteo*) and European Honey-buzzard (*Pernis apivorus*). In Germany this syndrome has been described in White-tailed eagles (*Haliaeetus albicilla*).

Ocular malformations: Developmental abnormalities affecting the eye have been infrequently reported in birds. Anophthalmia (the bilateral absence of eyes) and microphthalmia (the reduction in development of one or both eyes) are fairly common anomalies in embryos of the domestic fowl. A condition called colaboma or coloboma is usually congenital and is characterized by an absence of some portion of the eye. An adult Rough-legged hawk (*Buteo lagopus*) and a Red-tailed hawk (*Buteo jamaicensis*) both exhibited colabomas which involved a lack of development or an atrophy of approximately three fourths of the iris, lens, retina and choroids (Lord, 1956). Wallace (1956) described a case of microphtahlmia in an American robin (*Turdus migratorius*) and Wetherbee (1958) described unilateral microphthalmia in a Common Grackle (*Quiscalus quiscula*) and synophthalmia (cyclopia) in a Mockingbird (*Mimus polyglottus*). Another case of anophthalmia in an American Robin was recognized by Berger and Howard (1968). The eyeless bird exhibited a beak with the upper mandible being slightly shorter than the lower mandible. A potential eye-slit between the incipient eyelids was about 1 mm in maximum length in the anteroposterior direction bilaterally. In a survey of spontaneous ocular developmental abnormalities of raptors, various anomalies were recorded (Buyukmihci *et al*., 1988). These malformations together with other cases appear in Table 3. Varying forms of partial cryptophthalmos (a condition in which the eyelid skin is continuous over the orbit) have been reported in four cockatiels (*Nymphicus hollandicus*) by Buyukmihci *et al*. (1990). A new mutation of the chicken that causes a reduction in eyeball size, was described (Somes, 1992). Eyeball size reduction was extreme in over 80% of affected individuals. Two thirds of affected chickens had bilateral expression while the rest was unilaterally affected. Data from various crosses indicated that this condition is inherited as an autosomal recessive with expression being limited primary to females. The name microphthalmia-4 and the gene *mi-4* were proposed for this trait. Unilateral anophthalmia with beak deformation was found in a Western bluebird (*Sialia mexicana*) by Eltzroth (1996). In a 6-month-old Red-vented cockatoo (*Cacatua haematouropygia*) a congenital cause was considered for symblepharon between third and upper eyelids with secondary lagophthalmos (Kern *et al*., 1996). An inherited ocular anomaly was reported by Salter *et al*. (1997). Affected chicks had ocular lesions varying in number and severity, but both eyes were always affected. The earliest and most frequent lesions were dilated pupils, malformed lenses, buphthalmos and dysplasia of the pecten. Table 3 summarizes ocular defects in various birds.

Table 3: Ocular malformations in avian species

Species	Malformations	Reference
Common tern (*Sterna hirundo*)	Microphthalmia-anophthalmia	Gochfleld (1975)
Prairie falcon (*Falco mexicanus*)	Retinal dysplasia	Dukes and Fox (1983)
Golden eagle (*Aquila chrysaetos*)	Right microphthalmia	Buyukmihci *et al*. (1988)
Cooper's hawk (*Accipiter cooperii*)	Right microphthalmia; microphakia	Buyukmihci *et al*. (1988)
Red-shouldered hawk (*Buteo lineatus*)	Maldevelopment of ciliary body, choroid and pecten; retinal dysplasia	Buyukmihci *et al*. (1988)
Red-tailed hawk (*Buteo jamaicensis*)	Left microphthalmia	Buyukmihci *et al*. (1988)
Kestrel (*Falco sparcerius*)	Right ankyloblepharon; megalophthalmos; retinal dysplasia	Buyukmihci *et al*. (1988)
Perregrine falcon (*Falco peregrinus*)	Microphakia	Buyukmihci *et al*. (1988)
Barn owl (*Tyto alba*)	Microphthalmia; Left maldevelopment of pecte	Buyukmihci *et al*. (1988)
Great horned owl (*Bubo virginianus*)	Microphakia	Buyukmihci *et al*. (1988)
Screech owl (*Otus asto*)	Microphthalmia; uveal and retinal dysplasia	Buyukmihci *et al*. (1988)
Lesser snoe goose (*Chen caerulescens caerulescens*)	Monoexophthalmos	Rockwell *et al*. (2003)
Tippler pigeon (*Columba livia*)	Retinal dysplasia	Moore *et al*. (2004)
Sea eagles (*Haliaeetus albicilla*)	Microphthalmia	Muller *et al*. (2007)

Cardiovascular anomalies: Cardiovascular anomalies have been reported rarely in birds as clinical or post-mortem findings. In contrary, cardiac anomalies have been induced experimentally in chicken embryo models.

Siller (1958, 1967) cited a few references of congenital cardiac abnormalities such as ectopia cordis (displacement of the heart), duplicitas and multiplicitas cordis, aplasia, malposition and patent foramen ovale. The author (1958) recorded 288 cases of Ventricular Septal Defects (VSD) in domestic fowls. Most cases (97%) were confined to birds of only three inbred lines. Great variation existed in the general conformation of these septal defects and in the size of the communication between left and right ventricles. Three distinct types were differentiated: 1 large patent defects, 2 Small patent defects, 3 Completely closed defects. The study, on the incidence of congenital heart disease, in broiler chickens, continued by Siller and Hemsley (1966). The following forms of malformations were encountered: 10 cases of uncomplicated VSD, 8 cases of uncomplicated Atrial Septal Defects (ASD), 2 with combined ASD and VSD, 7 cases with septal defect and overriding aorta, 2 cases with transposition of the aorta to the right ventricle and one case of cor triloculare biatrium. In one chicken the carotid artery arose anomalously from the aortic arch. Consequently, the anatomical defects of previous study (Siller and Hemsley, 1966) as well as new cardiac cases were further analyzed (Siller, 1967).

Siller (1968) found an association between sternal fissure and congenital heart disease in the embryos and newly hatched chicks. Transposition of aorta to the right ventricle was observed in many chicks. Ventricular septal defects were observed in young Broad-Breasted White turkeys. In 2 cases a VSD was seen, but in another case gross structural evidence of naturally occurring closure of the defect was detected (Einzig *et al*., 1972). Nakamura and Itasaki (1991) found 4 chicken embryos in which the lateral endothelial heart tubes did not fused at the midline. In all the embryos, each heart tube looped independently, the right one to the right side and the left one to the left side. An umbrella cockatoo (*Cacatua alba*) had a ventricular septal defect and persistent truncus arteriosus whereas a Mollucan cockatoo (*Cacatua moluccensis*) had a subvalvular septal

defect and aortic hypoplasia (Evans *et al*., 2001). In a juvenile Houbara bastard (*Clamydotis undulate macqueenii*) that died suddenly, ventricular septal defect was found during the post-mortem examination (Bailey and Kinne, 2001).

Gastrointestinal malformations: Abnormalities of the gastrointestinal system have been documented in the avian veterinary medicine. In Gregory and Greaves (1947) reported a case of intestinal herniation in a 7 days old chicken which involved the duodenum, the pancreas and a major portion of the ileum and ceca. Later, A 6 day old White Leghorn male with a malformation involving the small intestine was described (Glick and Ellis, 1962). Duplication of the ileum was observed in a 4-month old Babcock pullet. Adjacent to the small persistent Meckel's diverticulum, a side branch projected out from the ileum and opened into a blind-ended sac-like structure near the cloaca (Grewal *et al*., 1976). The same authors described a case of aplasia of the left caecum in a 20-week old White Leghorn pullet. A case of a duplicated lower intestinal tract in a broiler chicken included a branched ileum (Chapman *et al*., 1997). The ileum of the malformed branch was swollen and attached to paired caecae that were grossly enlarged. The rectum was a swollen blind sac disconnected from the exterior of the bird. Congenital intestinal incarcerations were recorded in commercial broilers including Cobb, Arbor Acres and Ross breeds. The etiology of the problem assigned to the incomplete closure of the abdominal wall (Wojnarowicz and Olkowski, 2009).

Abnormalities of the liver and pancreas are rare. Grewal *et al*. (1976) described a case of vesica fellea occulta where the gallbladder was almost completely surrounded by liver tissue in a 7 month old White Leghorn pullet. In a 30 week old White Leghorn hen a bifurcation of the pancreas was recorded. Absence of liver lobes as well as missing or misplaced gall bladders in poultry birds reported by Tudor (1979). Additionally, a gall bladder anomaly in a 7-week old broiler cockerel referred as a spontaneous manifestation (Anderson and Miller, 1986). The cystic lumina contained multiple elongated papillary epithelial projections and plicae composed of epithelium and lamina propria, abutting normal lining epithelium.

Skeletal anomalies: Several localized skeletal abnormalities have been reported in birds, but a genetic etiology is usually difficult to prove especially when the number of cases is small. In many cases, abnormalities in a skeletal element are combined with other malformations.

A Herring gull (*Larus arginatus*) presented a grossly deformed bill (Threlfall, 1968). Thorough examination of the specimen's anatomy revealed malformations of head skeleton. The dentary and suprangular of the right half of the lower mandible were turned outwards and downwards. The left and right nasal bones and premaxillae were twisted to the right and downwards. The skull kinetics in birds attracted the attention of Burton (1972). In his study, a skull of a Rufescent Tiger-Heron (*Trigrisoma lineatum*) and a skull of a Black-necked Aracari (*Pteroglossus aracari*) were examined. The first specimen had a deformed orbital process of the right quadrate, whereas, the second specimen had a complicated anomaly involving the quadrate and the associate musculature. Particularly, the greater part of the orbital process of the quadrate was missing and the left M. pseudotemporalis profundus consisted of several portions. Research on the breeding biology and populations genetics of lesser snow geese (*Chen caerulescens caerulescens*) revealed developmental abnormalities of the head. A specimen displayed duplication of both upper and lower mandibles with the lower ones being medially fused. There were two normal-sized eye sockets and eyes on the lateral sides of the head and a single fused medial socket in the front of the skull that contained two eyes (Rockwell *et al*., 2003). Examination of the skull of a pink pigeon (*Columba mayeri*) revealed a failure of the right supraorbital ridge and the right premaxillary

process of the nasal bone to develop and an abnormal small and incompletely formed scleral ring (Waine, 1998).

The two elongated hyoid horns, composed of the ceratobranchial and epibranchial bones, extend posteriorly from the posterior end of the basihyal, curving around the occipital region and roof of the skull and extending forward along the dorsal cranial surface toward the nostrils (Wallace, 1974). Wallace (1974) studied several species of melanerpine woodpeckers and found that a surprising number of birds showed abnormal tongue development. The study involved examination of the Red-bellied woodpecker (*Centurus carolinus*), Golden-fronted woodpecker (*Centurus aurifrons*), Red-headed woodpecker (*Melanerpes erythrocephalus*), Hispaniolan woodpecker (*Centurus striatus*) and Puerto Rican woodpecker (*Melanerpes portoricensis*). The abnormalities in every case involved the position or relative size of the epibranchial horns with their attached branchiomandibularis muscles.

Deformities of the spine have been reported in poultry birds. Most of these reports describe scoliosis which is a malformation of multiple etiology including primarily genetic factors. Scoliosis has been described in the chicken (Chlumsky, 1924; Rigdon and Mack, 1968a) and in the white Pekin duck (*Anas platyrhynchos*) (Rigdon and Mack, 1968b; Rigdon, 1971). The spinal defect has been attributed to a persistent notochord and improper differentiation of spinal segments.

Rib anomalies in avian species were examined by Lucas (1888). His observations are listed in Table 4.

In a 22-week old White Leghorn hen a hernia-like swelling in the middle of the breast bone was observed. The caudal medial projection of the sternum (metasternum) was bifurcated in the middle into two small projections (Grewal *et al*., 1976) The same authors described another case of keel abnormality in a female White Leghorn chicken. The major defect was the absence of the whole of the sternal keel and the imperfect development of the major part of the metasternum ventrally (Grewal *et al*., 1980).

A four winged adult female Green-winged teal (*Nettion carolinense*) has been described from Johnson (1915). The supernumerary wings appeared as a miniature set springing from the under side of the primary wings at the region of the elbow. Stanton Grant Ernst (1943) reported a case of deformation in the wing of a pied-billed grebe (*Podilymbous podiceps podiceps*).The left wing was stunted with an apparent fusion of the carpal articulation.

Rogers and Dauber (1977) reported a case of a male with all toes missing on the right foot and the front middle toe missing on the left foot and a female with right rear talon missing. A spur

Table 4: Rib abnormalities in avian species

Species	Abnormality
Gray catbird (*Galeoscoptes carolinensis*)	Five pairs of complete ribs instead of six: seven pairs of ribs
Black catbird (*Melanoptila glabrirostris*)	Seven pairs of ribs with attached haemapophysis on the second vertebra of the sacrum
Bank swallow (*Clivicola riparia*)	
Crow blackbird (*Quiscalus purpureus*)	Additional pair of short slender ribs devoid of haemapophysis on the second vertebra of the sacrum
Western meadowlark (*Sturnella neglecta*)	
Ruby-throated hummingbird (*Trochilus colubris*)	Complete haemapophysis supporting a pleurapophysis whose upper moiety is lacking
Common swift (*Cypselus apus*)	
Great auk (*Alca impennis*)	Extra (ninth) pair of ribs on the second sacral vertebra

2 cm long was found in a 64-week old White Leghorn hen. Post-mortem examination revealed a well developed ovary. Grewal and Singh (1978). Developmental abnormalities in two British falcons were recognized by Cooper (1984). In the first case an immature female peregrine falcon (*Falco peregrinus*) exhibited duplication of hind digit (digit 1) on the left leg. The two digits, which appeared to be higher up the leg than normal, were joined by a web of skin. The bird also appeared to have two accessory digits on the left carpus. In the second case, a male merlin (*Falco columbaris*), a fusion of digits 3 and 4 on the right foot was detected. Three wingless pullet hens were discovered at an egg-production ranch. Two of the birds were amelic and one was ectromelic and all of them had also scoliosis (Ruble *et al*., 2002). A tawny owl chick (*Strix aluco*) with multiple congenital malformations in the limbs was studied (Barreiro *et al*., 2003). The animal had dislocation of radius and carpometacarpus with abnormal nonfunctional fixation of ligamentum propatagialis. Also, most parts of the bones of the manus in both wings were absent.

Two cases of unilateral micromelia were described in wild juvenile little penguins (*Eudyptula minor*). The bird's left flipper was reduced in length and radiography demonstrated severe shortening and dysplasia of the humerus. Clinical examination revealed that the second bird was underweight (0.55 kg) but otherwise in good condition with subadult plumage and had probably only recently fledged. The left wing was markedly reduced in size and had limited range of elbow and carpal joint movement but sensation and motor control were normal. Radiography demonstrated a severe reduction in size and distortion of the humerus and shortening and fusion of the ulna, radius, metacarpals and phalanges. The furcula was asymmetrical because the left clavicle was slightly thinner and more radiolucent than the right and was also slightly deviated to the right side (Raidal *et al*., 2006).

In a House finch (*Carpodacus mexicanus*) total absence of the right leg was reported (Michener and Michener, 1936). No scar was visible and feathers were growing over the area where the leg should have been. Two similar teratological specimens of the Red-winged Blackbird (*Agelaius phoeniceus*), from different geographical areas were found in the course of artificially incubating eggs of this species (Wetherbee, 1960).The defect was observable in the neonates only by corrosion-staining-clearing techniques. The femora and humeri were crooked, the ilia and ischia were much shortened and delayed ossification at the distal ends of tibiae, tarsometatarsi, ulnae and radii was observed. A one-legged adult male brown-headed cowbird (*Molothrus ater*) has been described by Manwell (1964). The right leg was completely missing. Also, the pubis was absent whereas the ilium and ischium were defectively developed. No signs of musculature normally associated with the proximal end of the femur were detected.

A Mourning dove (*Zenaidura macroura carolinensis*) with three legs was described by Frankowiak (1962). One of the legs was normal whereas the second had another small leg growing from its tibia-tarsus joint. The third leg had only an inner and outer toe. Similar case was reported in a Sooty tern (*Sterna fuscata*) (Austin, 1969). In a male common snipe (*Capella gallinago*) an extra digit on the hallux (toe 4) on each foot was recorded. The right and left extra digits were 4 mm and 3.5 mm respectively (Fogarty, 1969). Polydactyly was observed in a ring-billed gull (*Larus delawarensis*). The extra foot elements on each leg originated distally from the median anterior portion of the tibiotarsus (Ryder and Chamberlain, 1972). Forsythe (1972) described in a long-billed curlew (*Numenius americanus*) a supernumerary digit attached to the medial aspect of the left hallux. The extra toe arose at the base of the hallux; it measured 4.5 mm with the claw whereas the hallux was 7.5 mm with claw. Changed phalanges in form and number were found on both wings (Trinkaus *et al*., 1999). In a female kestrel (*Falco tinnunculus tinnunculus*) polydactyly was

described. The bird had extra toes on the right foot and three extra toes in the left one. Additionally the bird presented an extra finger on the right wing. The occurrence of an ostrich (*Struthio camelus*) chick which hatched with four temporarily functional legs has been reported by Horbanczuk *et al.* (2004). The one day old chick was fully developed with complete feathers. The first pair of legs was normally developed whereas the second pair was thinner, pale but almost the same size as the first pair. Between the sacrum and the tail, a short vertebral column emerged ventrally out of the normal one. Attached to it on either side were apparently normal and functional lower legs from the tibiotarsus to the toes, while the femur was missing on both sides. An extra symmetrically located toe was found on each foot of one Vaux's swift (*Chaetura vauxi*) (Sakai, 2006). The author reported from his bibliographic survey 10 other cases of polydactyly in mallard duck (*Anas platyrhynchos*), Wilson's snipe (*Gallinago delicate*), Sooty tern (*Sterna fuscata*), Long billed curlew (*Numenius americanus*), Ring-billed gull (*Larus delawarensis*), Common nighthawk (*Chordeiles minor*), Common loon (*Gavia immer*), Common swift (*Apus apus*), Eurasian kestrel (*Falco tinnunculus*) and Eastern Screech-owl (*Megascops asio*). Apart from the supernumerary limbs there are also cases of diminished limbs.

An apparently new mutation that is associated with abnormal limb development appeared in a strain of Light brown Leghorn chickens (Smyth *et al.*, 2000). Mutants were characterized by the complete absence of the tarsometarsals, while severely hypoplastic development of the metacarpals was also present. The phenotype of the mutant (ametapodia-2) is inherited as an autosomal recessive (*AMET*A*).

Uro-genital anomalies: A hen presented two vents with the oviduct opening through the left and the rectum through the right. The two passages were separate throughout (Crew, 1928). Next year three cases of double vents associated with other malformations in the fowl were reported (Roberts *et al.*, 1929). In the first case, the two vents were of normal size, symmetrically placed and opened into a common cloaca. Aplasia of the right kidney and hypoplasia of the corresponding ureter was found in a 4-month old Babcock pullet (Grewal *et al.*, 1976). The same authors described a case of aplasia of the right kidney and ureter in a 10-week old White Leghorn pullet. In an extended survey of autopsies (Tudor, 1979), kidney tissue was reported absent on one side, or from posterior, middle, or anterior lobes, or from combinations of all three. Ureters were dilated in some birds whereas others displayed only remnants of ureters. The author discussed extensively the kidney anomalies in birds including quails and pigeons.

Morgan and Kohlmeyer (1957) have described an inbred line of Rhode Island Reds with persistent right oviducts. The nesting behavior of a wild Giant Canada goose (*Branta canadensis maxima*) led Lumsden and Vernon (1983) to examine the genital system of the bird. The failure of the goose to lay was a result of a deformed and blocked oviduct. The funnel- shaped infundibulum was missing. Hereditary, persistent, right oviduct manifested in an inbred line (PNP/DO line) from the Fayoumi breed of chickens was investigated (Wakamatsu *et al.*, 2000). Females had varying lengths of elongated right oviducts, besides the normal left ovary and oviducts that generally possess, irrespective of their total length, regions similar to those normally observed in a left oviduct.

CONCLUSIONS

In the present bibliographical survey, the malformations of spontaneous and genetic nature were reviewed. The great part of the malformations involved the skeletal system. Another part

refers to ocular anomalies, feather anomalies and abnormalities of the heart, gastrointestinal and urogenital system. The majority of the developmental malformations that have been surveyed in the present review refer to anomalies that are easily observable by persons who are not necessarily specialized scientists such as ornithologists or avian veterinarians. Malformations which can not be recognizable and identifiable usually are disregarded.

The deformities of the birds reflect the status of their health as well as the status of their habitat. The abnormalities of the poultry populations are related mainly to inherited diseases. The abnormalities of the wild populations are related to more complicated situations which involve spontaneous, genetic, toxicological and environmental factors.

The present review summarized reports which together with the accounts of Romanoff (1972), Riddell (1975) and Crawford (1990) provide an extended database of developmental abnormalities. The report of such abnormalities serves to enrich the knowledge about the normal and abnormal development of avian species and in extension of the other animals and human beings. The scientists, ornithologists, veterinarians, foresters, bird-banners are encouraged to observe and refer such malformations to the authorized centers. The use of the data on abnormalities could be a potential bio-monitoring tool to assess changes in environmental conditions that are sufficient to have biological impact. This is the next scientific challenge of avian embryology and teratology.

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