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Description of head deformities in cultured common carp (*Cyprinus carpio* Linnaeus, 1758)

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ABSTRACT

Head deformities in cultured fish reduce their growth rate and survival, as well as degrading their external morphology, all of which can lead to considerable economic losses. While spinal deformities in cultured common carp have been analyzed in detail, relatively little is known about the prevalence, types or causes of head deformities. The aim of this study was to determine the prevalence of head bone deformities in 52 common carp, aged 2 years old, with spinal disorders from a farm in Croatia. Deformities were detected by clinical analysis, followed by detailed bone analysis, using X-rays and stereomicroscopy. Of the 52 fish, 8 (15.4 %) were found to have head deformities. Most deformities were bilateral and primarily affected the jaw arch and opercular string bone. Genetics and mechanical stress are proposed as possible causes of these deformities.

Key words: *Cyprinus carpio*, head bone deformity, jaw bone, opercular bone

Introduction

Skeletal deformities and injuries can occur in both wild and cultured fish (NOBLE et al., 2012). In Teleost populations, such deformities rarely occur in the wild (SLOOFF, 1982), but they are quite frequent on farms (KOUMOUNDOUROS et al., 1997). While such deformities and injuries can occur during any stage of the life cycle (NOBLE et al., 2012),

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they may be more prevalent among older cultured fish, because deformed fish tend to die early in the wild (COBCROFT et al., 2001).

Deformities and injuries can damage the external morphology of fish, rendering them less attractive to buyers, and they can reduce the growth and survival rates of cultured populations. All these effects can lead to major economic losses (DIVANACH et al., 1997). This highlights the need to understand the prevalence, types and causes of different deformities in order to guide farm management practices.

Previous studies of deformities and injuries have focused on spinal deformities in free-living and cultured fish (AFONSO et al., 2000; BACKIEL et al., 1984; DIVANACH et al., 1997; GJURČEVIĆ et al., 2007; GJURČEVIĆ, 2010; KAPOOR and SARKAR, 1955; KOUMOUNDOUROS et al., 2002). Much less is known about head deformity in fish, which involves the mouth or operculum and can occur independently of spinal deformity (BERALDO et al., 2003; TOFTEN and JOBLING; 1996) or in conjunction with it (AFONSO et al., 2000; ROO et al., 2010; SADLER et al., 2001). Several types of head deformity have been reported, including: cross bite, parrot-like head, pugheadedness, sucker mouth, “pinched jaw”, shortened or elongated upper jaw, shortened or elongated lower jaw, twisted lower jaw, mandibular joint deformity, double mouth, open jaw and lower jaw deformity syndrome (COBCROFT et al., 2001; FRASER and NYS, 2005; YADEGARI et al., 2011). Various factors, acting individually or jointly, have been shown to lead to deformities and injuries of fish heads: genetics, cultivation conditions, nutritional deficiencies, environmental contamination, mechanical trauma and infectious and parasitic diseases (QUIGLEY, 1995). The economic impact of head deformities in cultured populations highlights the need to understand much more about their prevalence and causes. Furthermore, to date, only a few studies have analyzed head deformity in common carp (AL-HARBI, 2001; BAKOS and GORDA, 2001; EISSA et al., 2009; KOCOUR et al., 2006; MRŠIĆ, 1936), and most of these studies did not identify the causes of the deformities.

The aim of the present study was to determine the prevalence, types and potential causes of head bone deformities in cultured carp from a single farm in Croatia. X-ray analysis and examination of bone preparations were used to gain a detailed understanding of the pathological changes involved. The results may guide efforts to reduce the prevalence of such deformities and avoid the associated economic losses.

Materials and methods

In this investigation, because of the increased prevalence of skeletal system deformities in common carp (*Cyprinus carpio* L.) on one fish farm in Croatia, and in order to exclude genetic factors as a possible cause of these changes, we placed special emphasis on broodstock selection for artificial propagation. All carp broodstock with determined skeletal system deformities and marked broodstock of the commercial common carp strain were isolated from further breeding. After the artificial spawning of the broodstock remaining in the broodstock population, no deformities of the skeletal system were noticed in the offspring. At the source farm, during routine health screening in the previous year, a total of 530 two-year old carp were examined for the presence of deformities and 52 fish with clinically visible skeletal system deformities were collected. For the purpose of this study, only fish with visible head deformities were examined macroscopically (Fig. 1a) and by X-ray, in two standard projections: profile (latero-lateral) and sagittal (dorso-ventral). X-ray images were taken using ortho films under two sets of exposure conditions (40 kV, 1.8-3.2 mA; 40-42 kV, 5-8 mA) and using mammographic films, under two sets of exposure conditions (43-48 kV, 11-14 mA; 52-55 kV, 16-22 mA). Overlap error meant that some potential bone changes did not appear clearly enough in the images for us to classify them as normal or deformed (Fig. 1b).

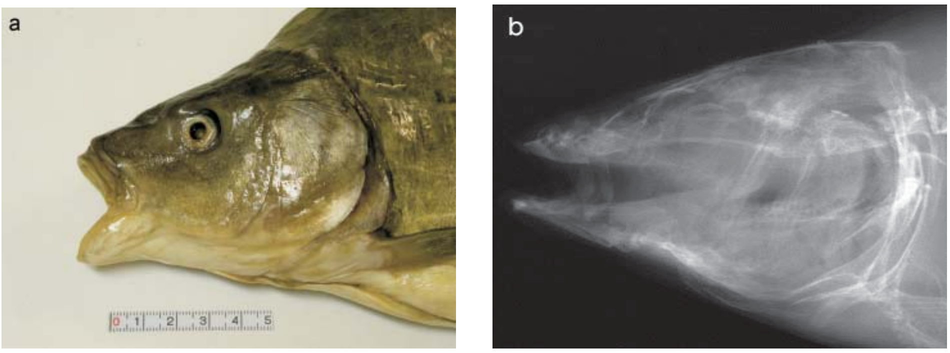

Fig. 1. (a) External morphology of the head of carp No. 2 in profile view; (b) Radiograph of carp No. 2 in profile view

To complement the X-ray data, we prepared skeletal samples for detailed examination of individual head bones. Soft tissues were removed by boiling in detergent, the cleaned bones were rinsed for 6 h in 10 % peroxide, and then the bones were analyzed using an Olympus SZX7 stereomicroscope and Olympus Cell B software. Pathological changes in bones were defined as deviations from bilateral symmetry or from the bones of intact carp of the same age (Fig. 2).

This study was carried out as a part of a larger scientific project on skeletal system disorders in common carp that has been approved by the Ethics Committee of the Faculty of Veterinary Medicine at the University of Zagreb. Methods were performed in accordance with Croatian laws and regulations.

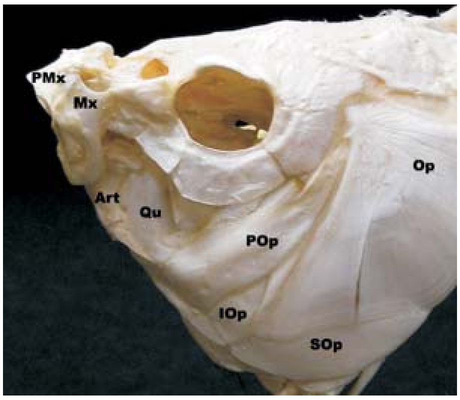

Fig. 2. Skull of intact 2-year-old carp. The following bones were examined in detail in head samples stripped of soft tissue: Art, os articulare; Cl, os cleithrum; Dn, os dentale; Hyom, os hyomandibulare; IOp, os interoperculum; Mx, os maxillare; Op, os operculum; PMx, os praemaxilla; POp, os praeoperculum; Qu, os quadratum; SOp, os suboperculum. Dn, Hyom, and Cl are not visible in the image because they are covered by an outer layer of bone.

Results

Head deformities (Table 1) were found in 8 (1.5 %) of 530 two-year old carp examined, and were found only in specimens that had spinal deformities.

On the basis of macroscopic examination, deformities occurred primarily in the upper or lower jaw (Fig. 3) and in the opercular region (Fig. 4). The deformities in all 8 carp were associated with changes in several head bones, though different bones were affected to different extents (Table 2). Microscopic analysis of bone samples, stripped of soft tissue, showed that most deformations occurred in the bones of the jaw and opercular string (Figs. 5-7).

Deformities involving shortening of the upper or lower jaw, altered bone position or altered spacing between bones (left and right PMx, Mx or Dn), were bilateral and symmetrical, with the exception of Carp No. 6 (Table 2). Deformities in this fish were more extensive on the right side of the head: Op and SOp bones were completely missing, as well as the caudal third of IOp. In addition, the first and second gill arches, medial to the Op, SOp and IOp, were missing, as was the ventral half of the third gill arch. The Dn, Art and Qu bones were not in their normal position and their shape was different from that in the reference carp. A sharp protrusion extended from the ventral side of the head in the area of the Dn-Qu joint. The left branchiocranial bones bent abnormally in the medial and ventral directions.

Table 1. Macroscopic identification of head deformities in 2-year-old common carp

Carp No.	Description of deformity
1	Length asymmetry between the upper and lower jaws (shorter upper jaw, longer and elevated lower jaw)
2	Length asymmetry between the upper and lower jaws (shorter upper jaw, longer lower jaw); abnormal bone position (“permanently open mouth”)
3	Shortening of the upper part of the head (“pugheadedness”)
4	Same as carp No. 1
5	Asymmetry of the maxilla (L/D): protrusion in the area of the opercular bone on the left side of the head
6	Asymmetry between the left and right jaw; lack of operculum on the right side of the head; morphological changes in the ventral part of the head
7	Narrowing and shortening of the front part of the head
8	Same as carp No. 7

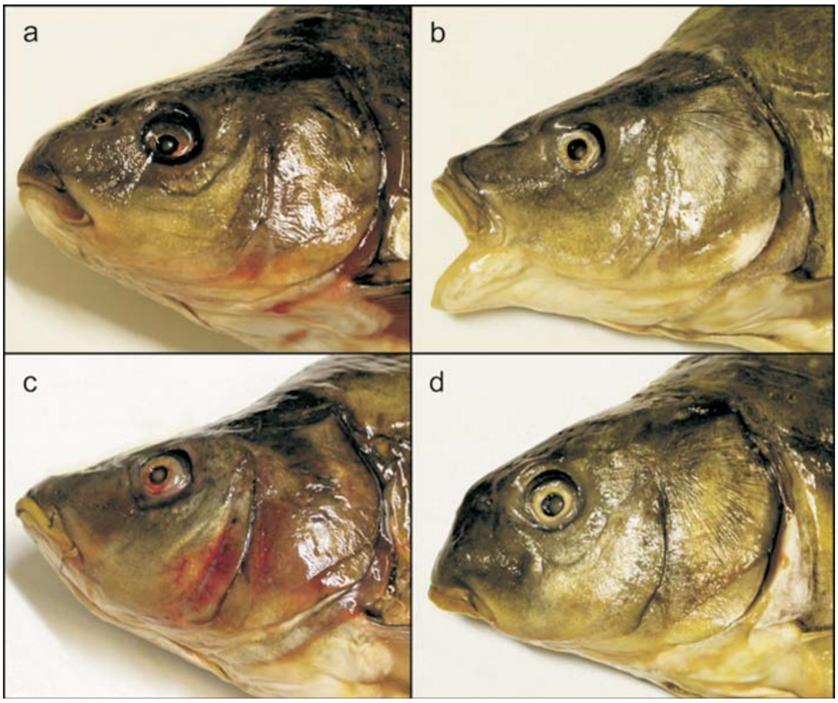

Fig. 3. Macroscopically visible bilateral head deformities: (a) narrowing and shortening of the front part of the head in carp No. 8; (b) “permanently open mouth” in carp No. 2; (c) shortening of the upper jaw along with elongation and elevation of the lower jaw in Carp No. 4; (d) “pugheadedness” in carp No. 3.

Table 2. Microscopic identification of head deformities in 2-year-old common carp

	1	2	3	4	5	6	7	8
PMx	L/D shortened	Vertical position of L and D (permanently open mouth)	L/D asymmetry; L shortened and thickened, D slightly thickened, higher at corpus part	L/D shortened	L/D asymmetry	L/D asymmetry; L proc. caudalis bent medially	L/D asymmetry; D shortened; narrowed interpraemaxillar space	L/D asymmetry; D shortened; narrowed interpraemaxillar space
Mx	L/D shortened	Vertical position of L and D (permanently open mouth)	L/D asymmetry; L shortened, crista Mx shortened, pars caudalis bent ventrally	L/D shortened	-	L/D asymmetry; L shortened and bent ventrally	L/D asymmetry; L proc. caudalis bent ventrally; narrowed intermaxillar space	L/D asymmetry; L proc. caudalis bent ventrally; narrowed intermaxillar space
Dn	L/D elongated	-	L/D asymmetry; L margo symphysicus flattened; D margo symphysicus wavy, proc. aboralis superior bent medially	L/D elongated	-	L/D asymmetry at proc. aboralis superior; D thickened at the corpus part	narrowed interdental space	L/D asymmetry; different thickness of proc. aboralis superior;
Art	-	-	L/D asymmetry; L shortened, facies articular quadrati modificated	-	-	L Art missing; D proc. articularis quadrati modificated	-	-
Qu	-	-	-	-	-	L Qu missing*, D whole bone deform in shape	-	-
Hyom	-	-	L/D asymmetry; D shortened for 1/3 of the length; proc. articularis pteroticus shortened, facies articularis modificated and thickened, bone's corpus wavy, crista praeopercularis bent laterally, proc. articularis opercularis flattened	L/D asymmetry; D crista praeopercularis doubled	L/D asymmetry at crista praeopercularis; L thickened at proc. inferior symplectici, proc. articularis opercularis and proc. articularis sphenoticus	L/D bone were missing*	-	L/D asymmetry at crista praeopercularis;

Table 2. Microscopic identification of head deformities in 2-year-old common carp (continued)

POp	-	-	-	-	-	L/D asymmetry; D bent on angulus superior	L/D asymmetry	L/D asymmetry; D shortened
Op	L/D asymmetry (at area rugae postarticulares)	-	L/D asymmetry; D shortened	L/D asymmetry; D margo superior bent medially	L/D asymmetry; L dented at facies externa	-	L/D asymmetry; D partial lack of the operculum in the lower third	L/D asymmetry; D partial lack of the operculum in the lower third
IOp	-	-	L margo and proc. superior bent medially	L/D asymmetry; D corpus dented at lateral side	-	-	L/D asymmetry; D reduced	-
SOp	L/D asymmetry (L bent media L/D elongated)	-	L/D asymmetry; L elongated, D bent medially	L/D asymmetry; D bend medially	L/D asymmetry; L shortened and bent medially		L/D asymmetry; D reduced	L/D asymmetry; L corpus bent laterally
Cl	-	-	L/D asymmetry; D spina dorsalis shortened	D narrowed at the middle corpus part	-	L/D bone were missing*	-	-

The following bones were examined in detail in head samples stripped of soft tissue: Art, os articulare; Cl, os cleithrum; Dn, os dentale; Hyom, os hyomandibulare; IOp, os interoperculum; Mx, os maxillare; Op, os operculum; PMx, os praemaxilla; POp, os praeoperculum; Qu, os quadratum; SOp, os suboperculum.

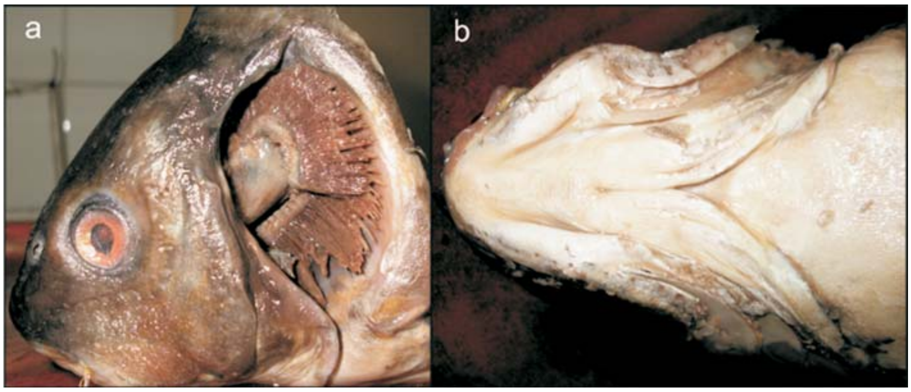

Fig. 4. Macroscopically visible unilateral head deformity in carp No. 6 in (a) lateral view and (b) ventral view

Fig. 5. Frequencies of deformities in specific head bones in 8 affected 2-year-old carp. PMx, os praemaxilla; Mx, os maxillare; Dn, os dentale; Art, os articulare; Qu, os quadratum; Hyom, os hyomandibulare; POp, os praeoperculum; Op, os operculum; IOp, os interoperculum; SOp, os suboperculum; Cl, os cleithrum.

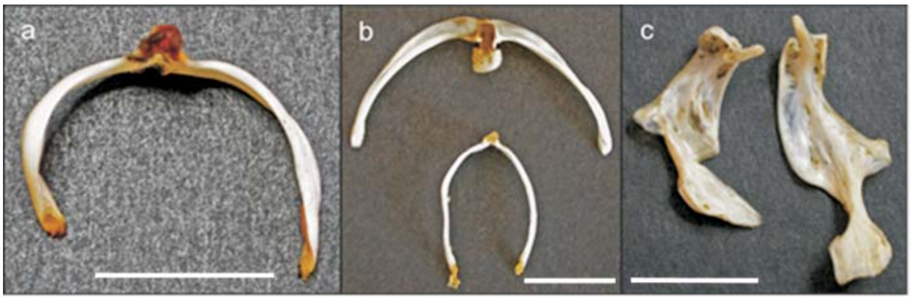

Fig. 6. Head bone deformities. (a) PMx of carp No. 3: L/D asymmetry with L shortened and thickened and D slightly thickened, higher in the corpus part (scale bare = 20 mm); (b, upper panel) PMx of carp No. 4: L/D asymmetry with L shortener than D and both L and D shorter than normal; (b, lower panel) PMx of carp No. 7: L/D asymmetry with D shortened; narrowed interpraemaxillar space (scale bare = 10 mm); (c) Mx of Carp No. 3: L/D asymmetry with L shortened, crista Mx shortened, pars caudalis bent ventrally (scale bare = 15 mm).

Fig. 7. Head bone deformities. (a) Dn of Carp No. 6: L/D asymmetry at proc. aboralis superior and with D thickened at the corpus part (scale bare = 15 mm); (b) Dn of Carp No. 8: L/D asymmetry; different thickness of proc. aboralis superior (scale bar = 15 mm); (c) Hyom of Carp No. 3: L/D asymmetry with D shortened by 1/3 normal length; proc. articularis pteroticus shortened; facies articularis modified and thickened; wavy bone corpus; crista praeopercularis bent laterally; proc. articularis opercularis flattened (scale bar = 15 mm).

Discussion

Bone deformities occur more frequently in cultured common carp than in wild carp (GJURČEVIĆ et al., 2007), which is also the case in other fish species (KOUMOUNDOUROS et al., 1997; NOBLE et al., 2012; SLOOFF, 1982). This presumably reflects the fact that the abundance of food and absence of predators at fish farms allow deformed fish to survive. Human handling of carp during early stages of development can also lead to skeletal deformities. Since such deformities can predict future low-quality fry batches (ROO et al., 2010), farmers should understand the types and frequencies of deformities that they may expect to find. Here we provide one of the most detailed analyses of head deformities in cultured common carp. We show that 15.4 % of fish with spine deformities also had head deformities, most of which were bilateral and primarily affected the jaw arch and opercular string bone.

The following deformities were identified by macroscopic clinical analysis: length asymmetry between the upper and lower jaws, elevated lower jaw, permanently open mouth, pugheadedness, asymmetry of the upper jaw, protrusion in the area of opercular bones, lack of the operculm on one side of the head, asymmetry on the ventral side of the head and a narrowing and shortening of the front part of the head. All these changes have been observed and described in different fish species of different ages (AFONSO et al., 2000; AL-HARBI, 2001; FRASER and NYS, 2005). However, we believe ours to be the first study to document all these deformities in a single species.

More detailed bone analysis, using X-rays and stereomicroscopy, revealed deformities in the PMx, Mx, Dn, Art, Qu, Hyom, Pop, Op, Iop, Sop, and Cl. The bones most frequently affected were PMx, Mx and SOp. The most frequent bone deformities involved: asymmetry in length, thickness or position; bending of part of a bone or of the entire bone; and changes at articular surfaces. Each deformed carp showed deformities of greater or lesser severity in multiple bones.

All the deformities we observed occurred in fish with spinal deformities, whereas we did not observe any deformities in normal-spine fish from our sampling site. AL-HARBI (2001) also reported multiple deformities in a single specimen of common carp, but the etiology of these deformities was unclear. Environmental disruption, nutritional deficiencies and genetics, or a combination of these three factors, have been proposed as possible causes. On the other hand, KOCOUR et al. (2006) concluded that there is no genetic control of mouth deformities in studied common carp populations. Interestingly, KOCOUR et al. (2006) did not mention any spinal deformities in individuals with mouth and fin deformities.

In the present study, no deformities in the offspring were observed after broodstock selection and artificial spawning. This finding suggests genetic factors as a possible cause of deformities in the farm studied. However, further studies would be required to substantiate this hypothesis.

Only one carp was found to have a unilateral head deformity: carp No. 6 showed a unilateral lack of opercular bones. This defect seems most likely to be due to a direct mechanical insult, given that the fish also lacked the first and second gill arches and showed damage on the third gill arch.

Understanding the possible causes of head deformities may help guide efforts to reduce their prevalence.

Conclusion

A substantial proportion of cultured common carp fingerlings showed diverse head deformities that may have a genetic basis. These findings are the most detailed so far for carp, and may help provide the basis for improving veterinary supervision during key growth and development stages, including the selection of parents, larval development and ossification. Future work should aim to record data on all factors that may affect the incidence of deformations, such as spawning and rearing conditions, type of diet and fish handling procedures. Analyzing these data will help separate the genetic and non-genetic causes of deformities and guide efforts to predict and reduce their incidence.

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SAŽETAK

Deformacije glave u uzgajanih riba smanjuju njihov rast i preživljavanje te narušavaju vanjski izgled što dovodi do znatnih ekonomskih gubitaka. Deformacije kralježnice uzgajanog šarana istražene su vrlo detaljno dok se o učestalosti, vrsti ili uzrocima deformacija glave malo zna. Cilj ovog istraživanja bio je utvrditi prevalenciju deformacija glave u 52 dvogodišnja šarana s jednog ribnjačarstva u Hrvatskoj kojima su utvrđene deformacije kralježnice. Deformacije su otkrivene kliničkim pregledom te istražene rendgenološki i uz pomoć lupe. Od 52 šarana 8 (15,4 %) ih je imalo i deformacije glave. Većina deformacija je bilateralna, a najčešće su bile zahvaćene kosti čeljusnog luka i operkularnog niza. Genetska predispozicija i mehaničko djelovanje navedeni su kao mogući uzroci utvrđenih promjena.

Ključne riječi: *Cyprinus carpio*, deformacije glave, kosti, čeljusni luk, operkularni niz

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