POSSIBLE CONTRIBUTIONS FOR THE DEVELOPMENT OF EXAPTIVE THEORY: THE EXAMPLE OF RACHIS

Mario Tanga, Giacomo Gelati

Corpus (International Group for the Cultural Studies of the body)

Abstract. Aiming at finding an objective method to define as exaptive (or as not exaptive) an evolutionary transformation, we can use a morphological and morphometric analysis of vertebras that can be realized through laser scanner technology. So we can reach a comparative valuation of rhachidian exaptive transformations from a typology of animals to another. In our work we referred to vertebras of a mammal tetrapod (chamois), of aquatic mammals (common fin whale, bottlenose dolphin) and of Man. We can suppose that the evolutionary transformation of the examined organ, system or structure is exaptive if: i) it remains the same under the phylogenetic/genetic profile, in other words it is the homologous; ii) it remains the same (exactly the same or however within certain limits that must be quantified by opportune indicators/descriptors) according to the morphometric/morphologic aspect; iii) its successive function changes with discontinuity if compared with the previous one; this aspects can be studied by modal analysis and by the model of *Eigenvectors* and *Eigenvalues*; iv) the new function is exclusive or however is prevailing on the original one. In particular, regarding rachis: i) we know the phylogenetic/genetic correspondence of this structure in all vertebrates; ii) we could choose some morphometric parameters as indicators of the maintaining/changing of structure; iii) we compare the previous and successive function under static/dynamic aspects. We refer to last year report, when we proposed that the evolutionary transformations of rachis static/dynamic function can be considered as exaptive. The functional transformation pushed us to rename human rachis as "*vertebral shock absorber*", due to its new vertical set-up, very different from the horizontal one that is proper of central axis (fishes and, later, of Cetaceous, even if in a different way), of beam (of tetrapods) and of shelf (of "partial" bipeds).

Key words: Exaptation; vertebral shock absorber; rachis; mechanical function; evolution.

"Evolution is an exaptive combinatory play in which new tricks are always teached to old genes."
(Francois Jacob, Exaptation, 1982)

Gutenberg took advantage of the already existing technologies: wine press, and movable type, combining them together, so to obtain the printing press.

Babbage "created" his Analytical Engine by "recycling" Jaquard's invention of punched cards that 30 years before were realized for managing mechanical looms automatically.

INTRODUCTION

Evolution is functional to expansion-maintaining of life. According to circumstances, expansion can be the same of maintaining or one between them can prevail on the other, or they can even be contradicting one another.

Life trend is maintaining-expanding itself. It owns both active and passive devices and sources functional to persistence of individual as much as of the species. From surviving instinct to capability of restoring structures or functions that are altered by pathological or traumatic processes, from reproduction instinct to enzymatic mechanisms that "correct" errors of DNA duplications, from homeostatic processes to negative feedbacks.

However there is a background noise that is never extinguished (genomic and epigenetic mutations, phenotypic plasticity) allows life to explore the space of state of adaptive and evolutionary possibilities in a random way.

In both cases of the single individual that adapts to context of the moment and of an evolutionary drift of long term, however it is changing capability. This capability must not be meant as possibility that remain silent, if nothing actives it. Moreover it is a connatural condition of life, an inextinguishable motion trend.

We notice two dialectical relations: i) between the trend to persist and the one to changing, and ii) between transformation factors and environment.

Persisting devices and variation ones are in a continuous dialectic relation, no one between them acts in an absolute way, but it is always somehow balanced by

Correspondence to:
Mario Tanga,
Corpus (International Group for the Cultural Studies of the Body)- http://corpus.comlu.com
E-mail: m.tanga@tin.it

its counterpart. background noise does not allow immobility stops everything. Stability trend slows down, limits, filters trendy changing, it avoids that they become exaggerate and dangerous drifts, that they become uncontrollable and can beneficiate of feedback.

The dialectic of this mobility with environmental, orients it toward directions that *a posteriori* become recognizable, interpretable, explainable.

This dialectic is made by continuous feedbacks. Each feedbacks are independent one from another. They can be considered as point-like?. The direction of changing (both adaptive and evolutionary) emerges only from the fact that many of these feedbacks compose with a certain level of convergence. No change is without consequences and only very few of them are neuter and indifferent. Somehow they always bring advantages or handicaps. Some variations of these ones obtain advantages that are the feedback that confirm themselves. Other variations are eliminated by selection. From this combination of confirming/denying an emerges the orientations of evolutionary transformations.

Implementation of this process is the continuous interlocution of living and of livings with environment and with the contingence, functionally to adapt itself to context itself, that is to say to make surviving chance maximum. Surviving is not the simple avoiding of death, but it is the warranty of affirming its own dominium, first within the already conquered limits, but also to expand them in each possible direction.

If expanding dominium is possible, this must imply the confirmation within existent limits. If this is not possible, the bare persistence of the existent dominium or, at least, of what can be saved, is the goal for the moment. The main factor is surviving and maintaining the reproduction capability, so that expansion process is suspended and it is postponed to more favorable moments.

In general this is an opportunistic behavior, that is decided step by step, without any straight directional line. Direction is calculated and re-calculated moment by moment. The geometry of this line shows no big scale regularity, except for the fact that some transformation of these ones are the pre-condition for other ones or they open a set of possibilities that were denied until that moment (metaevolution). However only the single ("atomic") is properly directed. Nothing strange if only the addiction of many transformation comes back to a point which evolution seems to be passed through. But there is not cyclic trend nor reversibility, also if somehow we notice a "loop", a closed circle. Mammals came back to water, as Cetaceous, but they are not fishes again. In water environment Cetaceous compete with fishes, but structural and functional solutions are different.

Provenience features (the fishes' ones, in this case) have been replaced by "vicariance" (if we name them according with Alain Berthoz) by different ones that are equally effective. This means only that, even if the circumstances request the same adaptation, the same evolutionary answer is never actuated: too many factors are implied…

Same adaptive exigency can be implemented by different solutions (structural or functional) and the same structure or function can satisfy different exigencies. There is no biunivocal correspondence between anatomical/physiological source and its role in adaptive play.

Therefore vicariance is a distinctive mark of life. We can name the over described cross correspondence just as vicariance. Exaptation itself can be defined as the capability of a structure of satisfying an exigency which it is not phylogenetically developed for.

The frequency, the effectiveness, the extremely wide range of ways of actuating exaptation make us recognize it as a fundamental evolutionary mechanism, dialectically related with the "classic" one of "creating" a new apposite organ/system aimed to satisfy the adaptive exigency.

Simply, we could speak of primary or secondary function. We define the function as primary, if it remains the same or it changes with continuity ("classic" adaptation). We define the function as secondary, if it became different through a discontinuity (exaptation).

Coherently, we can notice not cyclic processes nor reversibility: the apparent coincidence of two different moments of evolution does not mean that evolution goes back: evolution does not forget. Even if evolution does not walk according to "wonderful and progressive destinies", its direction is only forward. So, if they must implement the same adaptive exigencies, this origins different adaptive modifications, even if somehow they are equi-functional.

The so named "living fossils" themselves are not hypostasis of a life form that has never had reasons to change, but they represent the maintaining of some features thanks to globally neuter fluctuations, while other vary. Maintain is only apparent or relative.

This process of "fluidity" of life forms, related to maintain adequateness to environmental conditions, must not overcome the surviving possibility limit and is implemented in two different ways, often reciprocally contemned.

i. Creating *new* structures and transform them during time, according to the exigencies of the moment; this is possible if among mutations there is one of these always beyond the limit of being adapt; this is the *adaptation*, when we observe a new structure that request time to affirm itself, we must think that each provisory step is advantageous: it cannot be originated or tolerated "waiting for" the conclusion of the process.
ii. Co-opting *existing* structures that execute certain functions to convert them to "new" ones, that is to say they differ more than a discriminating limit (how can we determinate it under the qualitative and quantitative profile?) if compared with the original ones, there is "discontinuity of employing", it is the *exaptation*

In other words evolution uses two sources, or two proceeding ways: adaptive and exaptive. Now it uses one, now the other, according to which reacts before and better.

The central question of our work is: *basing our reasoning on these arguments, the human rachis can be considered a shock absorber that was produced by exaptation?*

In our opinion, during its history, rachis is the protagonist of two important exaptations. We hope science will give clarifications soon.

The first one between these two exaptation was the transformation from internal sustaining of the simple body of the proto-chordates (and moreover of fishes, almost without no fundamental functional variations) for their swimming and for a little more, to beam of tetrapods.

The second one is when the beam gains the vertical position, and due to this the rachis can be called (vertical) "shock absorber".

Both these passages was made possible by intermediate transitory conditions: between fishes and tetrapods with elevated trunk we find the slithering tetrapods. These have very limited problems of anti-gravitational sustaining, but the propulsive function of the tail fin (and of the whole body with the metachronal waves that generate lift in water) is replaced by ground reaction force (that are transmitted along the skeletal chain), generated by the action of the paws on the ground. When the trunk is no more leaned on the ground, the gravity is the main cause of transversal static solicitations, typical of tetrapods. This is the most relevant new function of rachis that makes us speak about "exaptative jump".

A brief parenthesis: when some terrestrial tetrapods come back to sea life(cetaceous) we have a new changement, but it is not symmetric to the previous. The meta-chronic waves are executed now on a different plane, perpendicular to the original one. The swimming movement has been reorganized and converge with the original ones regarding the function.

When the rachis becomes fully vertical, gravitational solicitations are mainly axial. The establishment of natural sagittal curves transforms the rachis in an effective shock absorber meant as a compression spring with a complex mechanical behavior.

The beam moves according to a wave-like pattern that makes it resemble to the rachis of fishes, but the resembling is cinematic rather than dynamic. This was the first exaptation. The second one is when the rachis underlies to axial static/dynamic charges and is made stable by a complex system of combined muscular tie rods, similarly to the stays of a mast.

Before the fully vertical position of the mechanical axis (that we can find in human structure), we can notice partially vertical positions, as in many bipods: kangaroos or apes, etc.

Their balance is less stable than the one of human body and needs compensative devices: the tail of kangaroo, the sporadic leaning of the knuckle on the ground (by apes).

The gravitational solicitations changes direction. From the transversal ones of the tetrapods these solicitations becomes oblique an reduce their angle until the direction of gravity coincides with the axis of the rachis. This new and different situation makes us propose the denomination of "exaptational jump" once more.

Aiming to maintain and to manage its balance, rachis uses tensegrity. This becomes the decisive factor when rachis is lacks of anterior/superior leaning. Meaningful examples are the neck of the giraffe or the rachis of bipeds, even with different inclinations of its mechanical and anatomical ax: kangaroo, apes, man...

A fleshy mass sustained by an internal semi-rigid axis, is a body plan that was established during the wonderful Cambrian explosion. This being is a proto-chordate. It lived in the water and nowadays Fishes' summary architecture is not very different from the one of this ancient and simple creature.

The wave-like movement on horizontal plane, moreover aimed to propulsion is furnished by a muscular motor that is a more or less continuous muscular mass: it is not organized in different and independent muscles as we find, for example, in Arthropods. Chordates' and Fishes' muscular mass has a metameric organization, whose elements are called "myomeres". These are strictly packed and surround the skeletal axis, acting on it and obtaining the simple wave-like movements. On the contrary, in the Arthropods a single muscle can act on a single articulation of external skeletal, obtaining a wide variety and combination of movements.

Proto-chordates can execute only the propulsive wave-like movements and some rough movements of avoiding an eventual predator, for example, and a little more.

No doubt bodily plan of Proto-chordates is less sophisticated than the Arthropods' one, but it allows to obtain a much more advantageous energetic efficiency. This will be more and more evident with the wide radiating differentiation of Vertebrates of later periods. If the external skeleton of Arthropods offer an energetic advantage on the soft body of worms (it is enough to compare the efficiency of a digger worm with the one of a Mole-Cricket), the internal skeleton allows a further jump of efficiency (now compare a Mole with a Mole-Cricket).

We can notice this superior efficiency also in the swimming: Fishes' speediness is incomparable with the Invertebrates' one, even if squids, with their "reaction" device, are very efficient.

The real difference will be very evident when Vertebrates will develop limbs and differentiated muscles instead of simple muscular masses as Fishes.

As we have already noticed, the bodily plan of internal axis remained similar to its original version until actual Fishes. A few of them (as Sole or Brill Fish) adapted their body to benthonic life turning it (and, together, the plane of movement) of 90°. A side takes the place of the ventral side and the other side takes the place of dorsal side. Another group of Fishes, Rays and Mantas, use the movements of the “wings”, that are still wave-like. These movements became prevailing on the body’s ones and they are realized according to a vertical direction, no more to an horizontal one.

Among the three fundamental kinds of Fishes’ swimming (strong acceleration, long distance and maneuver), only the last one is out of the schema and is realized thanks to pectoral fins that generate propulsion, moreover when the animal executes precision movements in small spaces, where irregular obstacles are present: the coral reef is the most typical example of this environment.

Strong acceleration swimming (see predators as the Pike), or the long distance one (see pelagic fishes as the Tuna) and even the swimming of the fishes that usually execute the manoeuvre one (when they swim for longer and more regular distances without obstacles) are very similar one another, and differ only for secondary parameters: however their base is the wave-like movement of the body on the horizontal plane.

Changing parameters are localization of junction points, wideness of angular/linear excursions of the tail fin (aimed to obtain the propulsive lift force), frequency of tail movements, but the essential swimming pattern remains the same. The unique interesting difference is the use of the pectoral fins to propulsive aims in swimming that is aimed to maneuvers, executing a rowing action. In this case pectoral fins have a function that is very different from the usual regulation of direction.

Anyway, in Fishes’ swimming, gravitational factor can be considered as absent: we find only fluid and internal frictions, inertial reactions and muscular forces. These are the main mechanic factors that involve Fishes’ rachis.

When first tetrapods go out from water, they lean the whole body on the ground to better contrast gravity. They must slitter and trail their body. Dry friction is strong, but it can be used through wavy movements in order to obtain locomotion. This movement pattern is directly inherited from their aquatic ancestors and now is supported by the contribute of the four limbs, that is synergic and coordinated with body waves.

The wavy movement is highly efficient and evident in snakes. Even if snakes have no limbs, they can be very quick thanks to wide flexibility of the body (their rachis is composed by a very high number of vertebras) and quickness of oscillation.

Later we find the elevation of the trunk, it is no more leaned on the ground. The weight of the animal is suspended on the two girdles: the shoulder (anterior) one and the pelvic (posterior) one. Only feet are leaned on the ground. Limbs become longer and stronger and each one is placed nearer the counter lateral one. walking is now quicker and running becomes possible. Running implies moments of full detachment from the ground!...

However the suspension of the trunk (it is now no more leaning on the ground) transforms the rachis from axial pillar to beam. Neck and head on the anterior pole and tail on the posterior one become a sort of shelves. Gravitational forces gain a new and different role both for shelves and for vertebral beam. They act on rachis according to a transversal direction. This mechanic condition is a very important factor (even if not the unique one) that contributes to limit the mass of terrestrial animals, differently from what happens in big Cetaceous.

The mass of the most gigantic herbivorous Dinosaurs is an exception, but maybe that at least they spent most of their time in a partial floating condition, with their body partially immerged in water.

It is a general rule that the scale factor limits animal’s dimensions (moreover of the terrestrial ones) through different aspects, but the rachis static/dynamic charge is surely among the most important ones.

In fact, when linear measures grow, the two dimensional ones (as bones sections – for mechanical resistance- and muscles sections – for the absolute strength) grow according to the second power, while the volumetric ones (linked to mass, inertial reaction, weight) grow according to third power. This means that when an organism changes its linear measures, the ratio between surface and volumetric parameters becomes very different, with the obvious consequences for physic/biological features. When linear measures grow, for example, the absolute strength, that is linked to only surface parameters (muscular section), grows much more, while the relative strength (linked to the ratio l^2/l^3, between muscular section and mass and weight) becomes lower.

A further evolutionary modification was the raising of the anterior part of the body: the anterior limbs are no more leaned on the ground. The mass is balanced on the transversal axis that crosses the hips. It is the beginning of the more or less stable bipedal asset.

A much more extended part of the rachis (from pelvis to head, no more only neck and head) becomes a shelf: the balance on the hip joint axis is not complete: the anterior mass is prevalent and trends to lean on the ground again. Bipedal position is maintained thanks to erector muscles of the rachis and to the extensors of the hip joints. Due to necessity of resting or to balance safety, often the bipedal position is abandoned for provisory regaining of quadruped one.

The unique mass that balance the anterior one is the tail. This can reach a conspicuous mass or length, in order to this function. See the Kangaroo, or the Squirrel, or the Lemurs. The anthropomorphic monkeys, that often use the bipedal position, use moreover the support of the knuckles of the superior hands.

Bipedal position reduces the surface of the polygon of support very much. Walking we have a further reduction: an only foot is leaned on the ground alternatively with both them.

This condition requests quick and exact postural adaptations, aimed to maintain the dynamic and static balance, even if, in extreme danger of falling, it is possible to use the quadruped support.

Homoeothermic regulation warranties quickness and efficiency of nervous and muscular systems and therefore it is indispensable for the bipedal balance and locomotion. For this reason Dinosauria, Aves, Mammalia were or are homoeothermic. This physiologic feature is even more important for big animals. Due to the already cited scale factor, if a small animal (of a few hundred grams or of a few centimeters) falls, it is very improbable that it receive an important trauma. If a big animal (as an elephant) falls, the traumatic consequences are very important and, probably, lethal. The decisive factors are the distance between barycenter and the ground (that determines acceleration and quickness of the impact), combined with the quantity of motion, that is widely due to the mass. The passive resistance to trauma is linked to the section of the structures, as the bones and other tissues. This ratio (between mechanic solicitations and resistance of organic structures) is less and less favorable when the bodily dimensions are bigger and bigger.

If Dinosaurs were not homoeothermic paleontologists should find the skeletons of the big bipods (*i.e.* the famous *T. rex*) with important traumas: it would be unavoidable for mechanic and statistic reasons. During its whole life, if it was not homoeothermic, such a big animal would have had many occasions of being bleary for the low environmental temperature and statistically it would have fallen. Paleontologists tell us that it did not happen, so this can be considered an even indirect proof of homoeothermic nature of bipod Dinosaurs.

The actual exception of “Lizard Jesus” (that is a Saur, not a Dinosaur) that runs on the water on only two limbs does not deny the rule. Bipod locomotion is realized in a few occasions and for a short time. Besides the animal has an exiguous mass and the water surface is not dangerous in case of impact…

In human beings the vertebral “shelf” of “occasional bipods” becomes a structure that till now has been named “vertebral column”. The lug wrench toward the anterior direction is very reduced or almost eliminated. The barycenter of the trunk is almost fully balanced on the axis of the hip joints. The verticality is much more advanced and the balance is much more stable, even if there is a residual trend of imbalance toward the anterior direction. However the balance can be maintained and managed, *ceteris paribus*, by a smaller muscular effort.

The postural difference is not only quantitative (the complete or almost complete extension of the hip joint): it is also qualitative: the global concave forward curve of the rachis, in Man is transformed in a series of shorter alternated curves on the sagittal plane.

We find four curves (cervical convex forward curve, thoracic concave forward curve, lumbar lordotic convex forward curve, sacral concave forward curve). The first three are mobile, the fourth one is fixed. The mobile curves make the human rachis a composite shock absorber, that works as a spring, moreover to be pushed, seldom to be stretched. Its mechanic resistance, if compared to an hypothetic rachis without curves, is ten times higher, according to the formula

$$R = n^2 + 1$$

where “R” is the resistance and “n” the number of curves. “n” = 3 offer a resistance ten times higher if compared to “n” = zero.

When human position of rachis was established (however this fact is evident also in anthropomorphic monkeys and even in other “partial bipods”), we notice a rotation of the main movements of the trunk. In Fishes and in Proto-chordates (as much as in quadrupeds) we find a meta-chronic wavy movements on horizontal plane, aimed to swimming and later to walking. In bipods are more important sagittal movements. Besides in bipods another movement gains importance: linked to walking and to running, we find rotation movement around the main axis (the vertical one) of the body: the shoulder diameter turns in a contrary sense of the pelvic one. This is aimed to maintain the frontal and balanced position while we walk.

The human rachis works according to its axial direction, against gravity. It is a fasciculate structure that is composed by three substructures. If observed in a transversal section, they are disposed as a triangle. On the anterior side, along the medial plane, we find the bodies of the vertebras alternated to inter-vertebral discs. On the posterior side, symmetrically, we find the two lines of the articular processes. These are linked to vertebral bodies thanks to stems pedicles. These three substructures are parallel and form a unique functional system. According to our opinion, this system could be called “vertebral pilaster”, obviously in the case of human rachis, that is unique among all animals. However the name of “pilaster” refers only to the static function. But due to the main function of our rachis the label of “shock absorber” is more proper.

The real novelty is the different distribution of the gravitational stress (meant both as punctual or distributed stress), if compared with the situation of the beam. Before bipedal (vertical) arrangement of the body, the function of shock absorber was carried out by limbs, not by rachis. Due to this rachis is deprived of the elastic-viscous component. Differently man entrusts the role of elastic-viscous shock absorber to the rachis itself. The stress is no more applied to the rachis perpendicularly (creating an angular momentum), but it is applied as co-axial. This causes a compression or traction (when the body is suspended or hung). However we always have pression mixed with flexion, due to physiological curves or to other causes of a never perfectly vertical direction of rachis. This indicates us that in mathematics and in engineering there is the possibility of a modelization of human rachis as an harmonic oscillator with n degrees of freedom.

In the movements around longitudinal axis, each vertebral body make a rotation, related to the contiguous one, thanks to the torsion of the discs.

Articular surfaces slip reciprocally according to main vertebral movement. Amounting all the rotations/torsions of each metamere we have the global torsion of the rachis and the rotation of an extremity regarding the other.

In each other movement we have always the elasto-plastic deformation of discs and the slipping of the articular surfaces.

This is a well known story. Starting from it we pose our question. Our observations are based on the exposed facts. If compared to the original proto-chord, the function of axial support has made some evolutionary jumps. From water (hydrodynamic propulsion) to land (leaned on the ground and later suspended as a beam), to elevation of anterior limbs (only pelvis sustains the charge of bodily weight, without the support of the shoulder girdle), to the more complete verticality of human rachis, including the peculiarity of the physiological curves.

Many factors have changed: i) mechanic solicitations (gravity instead of fluid friction and so on); ii) quantitative parameters (vector modules, their direction and sense…); iii) cinematic equations (mathematic models of different kinds of motion, to calculate speediness, accelerations, shakes…); iv) biomechanical functions (shock absorber, spring to be pushed/stretched, instead of pillar aimed to warranty swelling to bodily mass and efficiency to meta-chronic waves; v) main plane of movement (no more the coronal plane, but the sagittal and transversal ones).

No doubt, during this long evolutionary drift of rachis, there are also factors of functional continuity: generically rachis has always been an interior sustention, but the discontinuity cannot be ignored.

This ambivalence can be detected also in some widely demonstrated exaptations.

Swimming bladder is a cave organ whose gaseous content is controlled and regulated as much as in the lungs, even in these two cases, this function is differently aimed.

Feathers as thermal device interact with air, and so happens for the flight organs, even in a different way and for different aims.

And penguins' wings? Their use has converged with the one of the pectoral fins of Fishes. Due to this reason, is this transformation definable as exaptation? The same question can be posed for the limbs or ex-limbs of Cetaceous or Pinnipeds, or, *illo tempore*, of Ichthyosaurs. These structures have converged toward Fishes' fins.

When some snakes go forward through rectilinean motion (some author names it "caterpillar"), they create grip and propulsion, managing ventral scales as small crammed paws of myriapods, where flows metachronal waves. Scales evolved as mechanical defense of the reptilian body, not as locomotion appendixes.

The case of the elephant's trunk is a different case: would that nose become so long and so powerful, if it should not carry out tasks that are different from the respiratory ones?

The dentine is a further different case. It sprang in fishes as somatic protection. Later, in other vertebrates, it migrated on teeth's surface. Can we consider this repositioning as a transformation, so we do not name it as exaptation?

The prehensile tail of certain monkeys works as a fifth limb and it is a very important role in arboreal locomotion of the animal. the vertebrates' tail has the function of compensating for asymmetrical movements, overall the walking of tetrapods, and of balancing body in symmetrical movements or postures, for example in bipedalism of animals as kangaroo or squirrel. The grasp (that allows the animal to be suspended or to climb) is a function that is obtained through exaptation?

Was this evolutionary transformation an exaptation?

The first exaptation was the transformation of fins in limbs in the tetrapods, when vertebrates conquered the terrestrial environment. Sustaining the body's weight and pushing it forwards thanks to attrite and to vinculum reaction, is a fully different task if compared to swimming in a gravity free environment.

We know that evolution is an irreversible process: it doesn't come back to its origins erasing the transformations that happened in the meantime. Well: the passage from limbs to fins is not the reverse of the previous passage from fins to limbs. It is a further and different passage.

The same question could be legitimated about many other transformations.

No doubt these jumps imply quantitative and qualitative variations. The question "Exaptation or not exaptation?" can be posed each time.

Other hierarchically more general and more important questions can be posed: i) Can we establish a criterion according to which the change of function (and, even marginally, of structure) can be defined "functional cooptation", so that the definition of "exaptive" can be legitimated? ii) Can we build a detailed model of this protocol of examination and classification of the evolutionary transformation? iii) Can we structure a taxonomy of indicators and descriptors on which we can base our interpretations? iv) Can the phenomenon be quantified (not only qualified)?

We hope to have answers in a near future…

And, during the evolutionary drift, how many convergences and analogies could arise this question?

These jumps imply qualitative and quantitative variations in an absolute way. The remaining problem is if they can be named "exaptations" or not.

This is a difficult question for scholars in the future…

APPENDIX

Even if many things may be changed, the following suggestions can be useful.

We think that some factors can be meaningful in indicating the maintaining or the transformation of the rachidian structure. These factors must be defined with a more exact and articulated criteria, but nevertheless it can be important they are indicated, even if summarily:

- Regionalization. Number of regions (it is the same or it is different) and number of vertebras in each region (it is the same or it has an increase/decrease of a certain percentage, up to 20%, up to 40%, ...). Under the genetic profile it is important to compare the function of Hox genes.
- Index of flexibility.

$$If = \frac{(Iv\ D\ G)^{\wedge}\ 2}{(Iv\ D\ d)(V\ G)}$$

If = Index of flexibility
Iv D G = Intervertebral Disc Gauge
Iv D d = Intervertebral Disc diameter (transverse or sagittal)
V G = Vertebral body Gauge

- Ratio between (transversal or sagittal) diameter and gauge of vertebral body
- Angulation of transverse processes in projection on transverse plan (within a certain value or wider)
- Angulation of transverse processes in projection on sagittal plan (within a certain value or wider)
- Angulation of spinous processes in projection on sagittal plan (within a certain value or wider)
- Presence/absence of the homologous processes
- Extension of muscular insertion surfaces on vertebras (especially on the processes)
- Ratio between vertebral volume and whole body volume
- Vertebral density
- The comparison is to be made between homologous vetebras (of the same segment).

We would like to focus that these parameters can be easily detected and compared thanks to laser scanner surveying.

BIBLIOGRAPHY

Bock WJ. Preadaptation and multiple evolutionary pathway. Evolution 1959;13:194-211.

Compagno L. Coelacanths: shark relatives or bony fishes. San Francisco: California Academy of Sciences; 1979.

Cowen R. History of life. 5th ed. Chichester: Wiley-Blackwell; 2013.

Darwin C. On the origin and transitions of organic beings with peculiar habits and structure. In: On the origin of species. 1st ed. London: John Murray; 1859. pp. 179-186.

Dhaval KP, Pritha SB. A morphometric study of the pedicles in dry human typical thoracic vertebrae. Int J Curr Res Rev 2014;18:10-5.

Ehrlich P, Feldman M. Genes and culture: what creates our behavioral phenome? Curr Anthropol 2003;44:87-107.

Eshel I, Matessi C. Canalization, genetic assimilation and preadaptation: a quantitative genetic model. Genetics 1998;4:2119-33.

Farmer C. Did lungs and the intracardiac shunt evolve to oxygenate the heart in vertebrates? Paleobiology 1997;23:358-72.

Fisher SE, Whitt G. Evolution of the creatine kinase isozyme system in primitive vertebrates. San Francisco: California Academy of Sciences; 1979.

Forey P. Blood lines of the coelacanth. Nature 1979;351:347-9.

Gould SJ, Vrba ES. Exaptation - a missing term in the science of form. Paleobiology 1982;8:4-15.

Gould SJ. Exaptation: a crucial tool for an evolutionary psychology. J Social Issues 1991;47:43.

Guglielmi G, Diacinti D, van Kuijk C, et al. Vertebral morphometry: current methods and recent advances. Eur Radiol 2008;18:1484-96.

Hall BK (ed). Fins into limbs: evolution, development, and transformation. Chicago, London: The University of Chicago Press; 2007.

Hayden EJ, Ferrada E, Wagner A. Cryptic genetic variation promotes rapid evolutionary adaptation in an RNA enzyme. Nature 2011;474:92-5.

Head JJ, Polly PD. Evolution of the snake body form reveals homoplasy in amniote Hox gene function. Nature 2015;520:86-9.

Jacob F. Evolution and tinkering. Science 1977;196:1161-6.

Lagios M. The coelacanth and the chondrichtyes as a sister group. San Francisco: California Academy of Sciences; 1979.

Lombardini JB, Pang P. Amino acids and taurine in intracellular osmoregulation in marine animals. San Francisco: California Academy of Sciences; 1979.

Masel J. Cryptic genetic variation is enriched for potential adaptations. Genetics 2006;172:1985-91.

Mayr E. the growth of biological thought: diversity, evolution, and inheritance. Harvard: Harvard University Press; 1982.

McCosker JE, Lagios M. The biology and physiology of the living coelacanth. San Francisco: California Academy of Sciences; 1979.

McCosker JE. Inferred natural history of the living coelacanth. San Francisco: California Academy of Sciences; 1979.

Moyle PB. Fishes: an introduction to ichthyology, edgewood cliffs. New Jersey: Prentice-Hall Inc.; 1988

Neill WE. Induced vertical migration in copepods as a defence against invertebrates predation. Nature 1990;354:524-6.

Nicolosi P. Variabilità intraspecifica in Delfino comune, Delphinus delphi (Linnaeus, 1758). L'utilizzo della morfometria geometria bi- e tridimensionale come strumento diagnostico e conoscitivo. Tesi di dottorato, Università del Molise, A.A. 2010-2011.

Okada N. Emergence of mammals by emergency: exaptation. Genes Cells 2010;15:801-12.

Patterson C. The contribution of paleontology to teleostean phylogeny. New York: Plenum Press; 1977.

Patterson C. Rosen DE. Review of ichthyodectiform and other mezoic teleost fishes and the theory and practice of classifying fossils. Bull Am Mus Nat Hist 1977;155:81-172.

Pisani D, Laura L, Poling LL, et al. The colonization of land by animals: molecular phylogeny and divergence times among arthropods. BMC Biol 2004;2:1.

"Preadaptation" Merriam-Webster Online Dictionary. 2009. Available from: http://www.merriam-webster.com/dictionary/preadaptation.

Rajon E, Masel J. Evolution of molecular error rates and the consequences for evolvability. PNAS 2011;108:1082-7.

Smith JLB. The sea fishes of Southern Africa. Capetown: Central News Agency; 1949.

Smith JLB. The search beneath the sea. New York: H. Holt & Co; 1956.

Thomson KS. Living fossil: the story of the coelacanth. New York: W.W. Norton & Co.; 1991.

Thomson KS. The biology of lobed fined fishes. Biol Rev 1969;44:91-154.

Viglino M, Flores DA, Ercoli MD, Álvarez A. Patterns of morphological variation of the vertebral column in dolphins. J Zool 2014;294:267-77.

SITOGRAPHY

http://aaeweb.net/schedearticoli/anfibi/anfibi_anatomia.htm

http://www.ba.infn.it/~fisi2005/animazioni/simulazione059.html

http://object-e.net/tools/attractorfields-tools-gh

http://people.eku.edu/ritchisong/feather_evolution.htm

http://www.grasshopper3d.com/profiles/blog/list?month=05&year=2012

http://blogs.scientificamerican.com/thoughtomics/coelacanths-evolve-indian-ocean-is-home-to-distinct-populations/ (Coelacanths are not living fossils. Like the rest of us, they evolve), February 6th, 2012

http://www.scientificamerican.com/article/slow-evolving-lobe-finned-coelacanth-genome-unlocked/ ('Coelacanth' Genome Unlocked), April 17th, 2013

http://www.scientificamerican.com/article/modern-sharks-may-not-be-living-fossils-after-all/ (Modern Sharks May Not Be "Living Fossils" After All), April, 6th, 2014

http://www.scientificamerican.com/gallery/slowly-evolving-elephant-shark-offers-clues-about-why-some-fishes-have-no-bones/ (Slowly Evolving Elephant Shark Offers Clues about Why Some Fishes Have No Bones), January 8th, 2014