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A NEW METHOD FOR MEASURING MECHANICAL PROPERTIES FOR FISH VERTEBRAE[1]

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ABSTRACT

The use of ultrasonics is proposed for studying the mecanical properites of fish vertebrae in fisheries research. Bagrus bayad vertebrae are used for assessing their mechanical properities by ultrasonic measuremints. iternal fricrtion, ultrasonic wave belocity, and elasticity. The relationship between any one of these parameters and vertbrae characteristics (i.e., diameter, density, thickness, age of fish, and fish length are also evaluated, Based on statistical infernces of theses relationship, it is concluded that the (internal friction) parameter can used as an easy measure for mechanical propertieso of fish vertebrae.

INTODUCTION

Hamilton et al. (1981 a) developed a compression test meth-

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od for describing mechanical prperties of fish bone based on other animal bone studies. This method was adopted by Hamilton et al. (1981 b) and mehrle dt al. (1982) on feshwater Bmerican fish species. In this study, a non detructive ultrasonic technique is used to evaluate the mechanical properties of fish verebrae (e.g. Bagrus bayad).

MATERIAL AND METAHODS

Fish (Bagrus bayad as a modulus fish) were coected from Bahr Shebeen Canal and immediately brought and dissected at the laboratory. Three to 5 vertebrae, right below the dorasl fin, were taken out, cleaned from tissue and spines. They were then perserved in distilled water in labelled vials at 4°c. Records on the fish standard length (cm) and total weight (gm) were also included in the label. According to Hamilton et al. (1981 a). preervation in cold water and 6 to 8 fish per group are needed to give consistant results of mechanical properties, otherwise the fish vertdbrae would behave asd soil state material. However, 15 fish of rdlatively large size were used here in this study. Vertebre were dired at room temperature for 1/2 to 1 hour before testing.

The mecnical properties; internal friction, wave velocity and young's moduls elasticity; of vertebrae were measured by a method (Fig. 1A) that was early described for soild state physics by Bell and pelmore (1977) and subsequently by Khafgy (1985). In this method a magnetotrictive delay-line technique was cmployed, where a generated burst of mehanical oscillations were used to excite the tested vertebra at the natural frequency, or one of the harmonic vibrational frequencies of the wpecimen. The technique includes using a tranmission line wire, as the delay line, and cemented by araldite at its remote end to median point on the longitudinal external length of the vertebra. The signal echo resulted, or produced, by the passage of the ultrasonic wave through the verebra was recorded by the system as shown schimatically in figure 1B. This echo production on the oscilloscope screen is an indication of the proper use of the vertebrac in the introduced method. It also indicates that concavety of the verebrae did not interfere adversely with the resulant echo. The parameters illutrated in this figure (1B) were used to calculate the internal frcition Q^{-1}, al follows:

$$Q^{-1} = 1 / Q_m,$$

$$X = Q_e / Q_m = (A_o + A_{oo}) / (A_o - A_{oo})$$

$$\text{and TIN} / Q_c = \text{In} (2 / (1 - X) / (1 + X).$$

where Q_c and Q_m are the coupling and material Q-factors repectively. Accordingly. Q^{-1} can be calculated. The internal friction Q^{-1} represents all the mechanisms by which the vertebra is capable to cnergy or damp it internal. The ultrasonic save velocity inside the vertbra (Wv) can be calculated by the fomrula given by Mindin and Gagis (1960):

$$F_{O1} = 0.9342 (h / A^2)Wv$$

where FO1 = the observed vibration resonance frequency of the tested specimen as recorded by the frequency of the operated system, h= 1 / 2 thickness of the vertbra, A = the vertbra diameter. The value of Wv predicted by this fomula is used to calculate young's modulus elasticity as follows :

$$Wv = \sqrt{w / D (1-Q)}$$

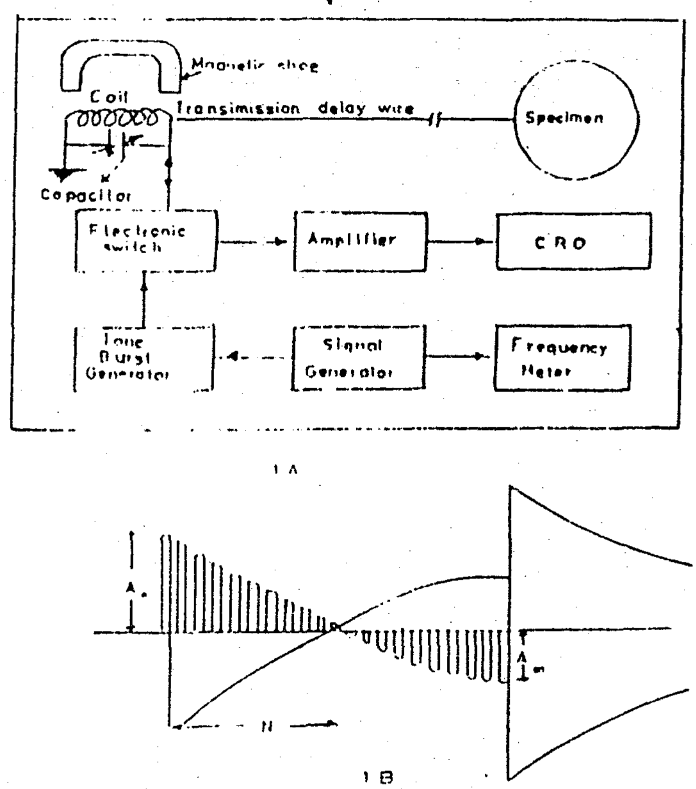

Fig. (1)
A : Diagram showing the apparatus used for evaluation of mechanical poperties of fish vertebrac.
B : The measurable parameters of the echosignal ; intial amplitude (Ao). steady state)A) amplitude, and number of oscillations to cross over (N).

Where D = vertebra density. Q = poisson's ratio and W = yong's modulus elasticity. For simplicity, E was clculated as Wv as Wv^2 multiplied by D.

Thickness of vertebrae was mesured by a micrometer. Vertebrae Diameter was edtermined by Vernier caliper and density by Archimides principle. Age of fish was determined by counting number of the trre ring under light microscope. Rings as annuli were validated in vertebrae of B. by Khallaf and Authman (1991).

RESULTS

Vertbrae thickness and diameter, but not density, are found to correlate significantly with lenght of fish as follwos:

T = 0.0622 + 0.0089 L (r + 0.799; Fig. 2A)

and Di = 0.1679 + 0.0026 L (r = 0.8566; Fig. 2B)

where T = vertebra thickness in cm, Di = vertbra diameter in cm, L = fish standard length in cm, and r = cooelation coeffectint.

Arranging the data per vertebra diameter interval of 0.10 cm, the relationships between diameter. thickness or density are found significant. However, density data are arranged in intervals per 0.02 an interval of thickness in their relationships and these are :

T = 0.2152 + 0.2586 Di (r = 0.87; Fig. 3A)

D = 1.9p62 - 0.5714 Di (r = 0.91; Fig. 3B). and

D = 1.7178 - 0-.7918 T (r = 0.88; Fig. 3c)

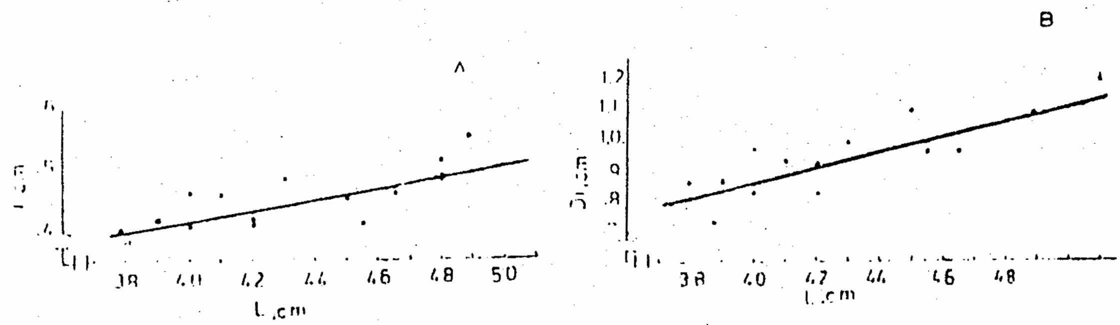

Figure (2)
Change in thickness (T; Fig. 2A) and diameter (Di; Fig. 2B) of vertebrae with fish length with fish length (L) variations.

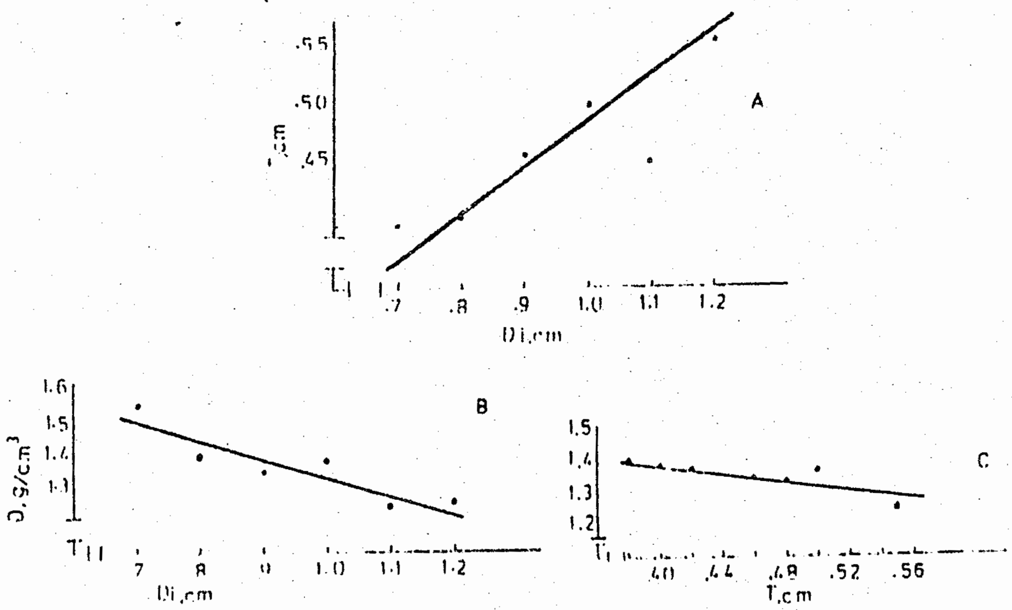

Fig (3):

Morphological relationship of vertebrae: (3A) thickness (T) and diameter (Di) , (3B) density (D) and diameter (Di), and (3C) density (D) and thckness.

where D = density of verterae, Di = diameter of vertebrae in cm an dT = thickness in cm of vertebrae. When the partial corrclation coefficint os considered for any possible combination between two parameters while the third parameter is constant; the relationshop between density and diameter of the vertebrae is found to have a higher correlation coefficient (r = 0.62; Fig 6A) relative to the other two relationships.

Morphological data of vertebrae arrnaged per age (years) imdicated the following signficant relationships:

Di = 1.01 - 0.02 age	(r = 0.71; Fig. 4A) and
T = 0.4834 - 0.0134 age	(r = 0.91; Fig. 4B

When relationship between age and either parameter, in presence of the third conatant parameter is considered. age and thickness partial correlation coefficient os the most significant (r = 0.83). It is worth to mention that when age is considered conatant, thickness and diameter have a lower value of r (0.76); and that partial correlation coefficient between age and diameter is the least significant (0.38). These relationships are are shown in figure 6 A.

The ultrasonic and vertebral parameters have the following sinfificant relationshops:

Q^{-1} = 55.705 - 36.617 Di	(r = 0.76; Fig. 5A).
Q^{-1} = -52.398 + 56.43 D	(R = 0.79; Fig. 5B) and
Q^{-1} = 16.002 + 1.838 age	(r = 0.69; Gig. 5X)

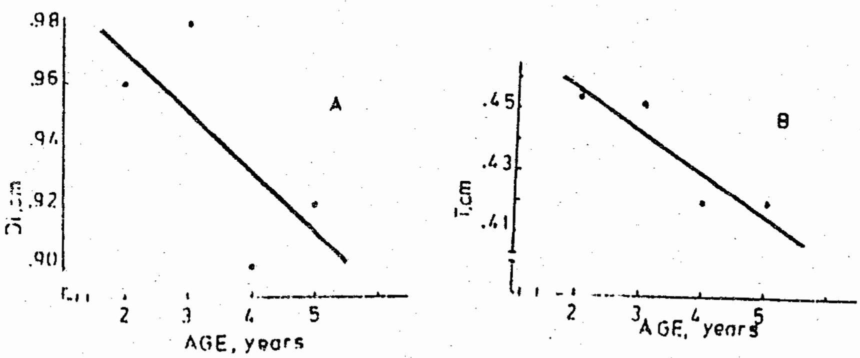

Figure (4)

Relationship between : (4A) age of fish and diameter (Di) of verebrae; (4B) age of fish and thickness (T) of vertebrae.

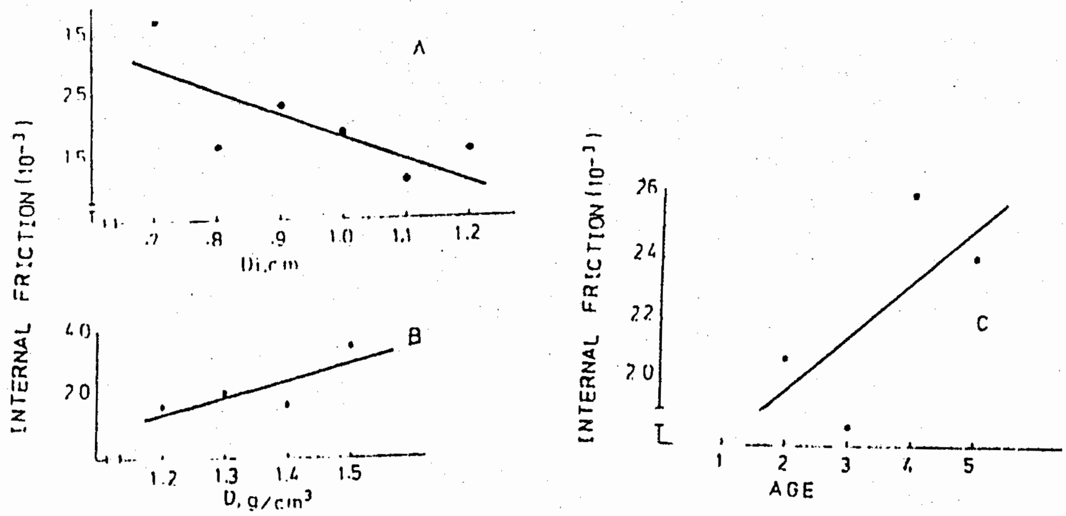

Figure (5) : Relationship between friction and (5A) deameter (Di) of vertebrae, (5B) density (D) of vertebrae, and (5C) age of fish.

If thickness is to be considered constant, the partial correlation coefficient between internal fiction and either diameter or density reses to 0.90 and 0.99 respectively (Fig. 6 B). The internal friction and verteebra thickness has a weak relationship (r = 0.41) but become significant when diameter is constant (r = 0.79) and even highly significant on constancy of density 9r = 0.909).

For ultrasonic wave velocity (Wv) and age of fish, the relationship is found to be as follows:

Wv = 181.8045 - 5.2591 age (r = 0.992; Fig. 7 A)

Vertebra elasticity followed a curve on relation to age of fish (Fig. 7B); but did not follow a trend when related to fish length. It is needless to say that elasticity of vertebra could not be correlated to either diameter or thickness or density because these parameters were used in its calculations. The same is applied for Wv and T or *Di relationships.*

DISCUSSION

The morphometric characters of vertebrae showed that the partial correlation coefficient are found smaller than the direct corrdlation coefficient between any two parameters. This is quiet understandable since all of these parameters are subject to changes due to environmental ro biological variations. Verbebral defomities could be caused by hereditary factors during embryonic stages . unfavourable water temperature, low dissolved oxygen, nutrition deficiency and infection (Bengtsson 1979). Moreover, size at age can

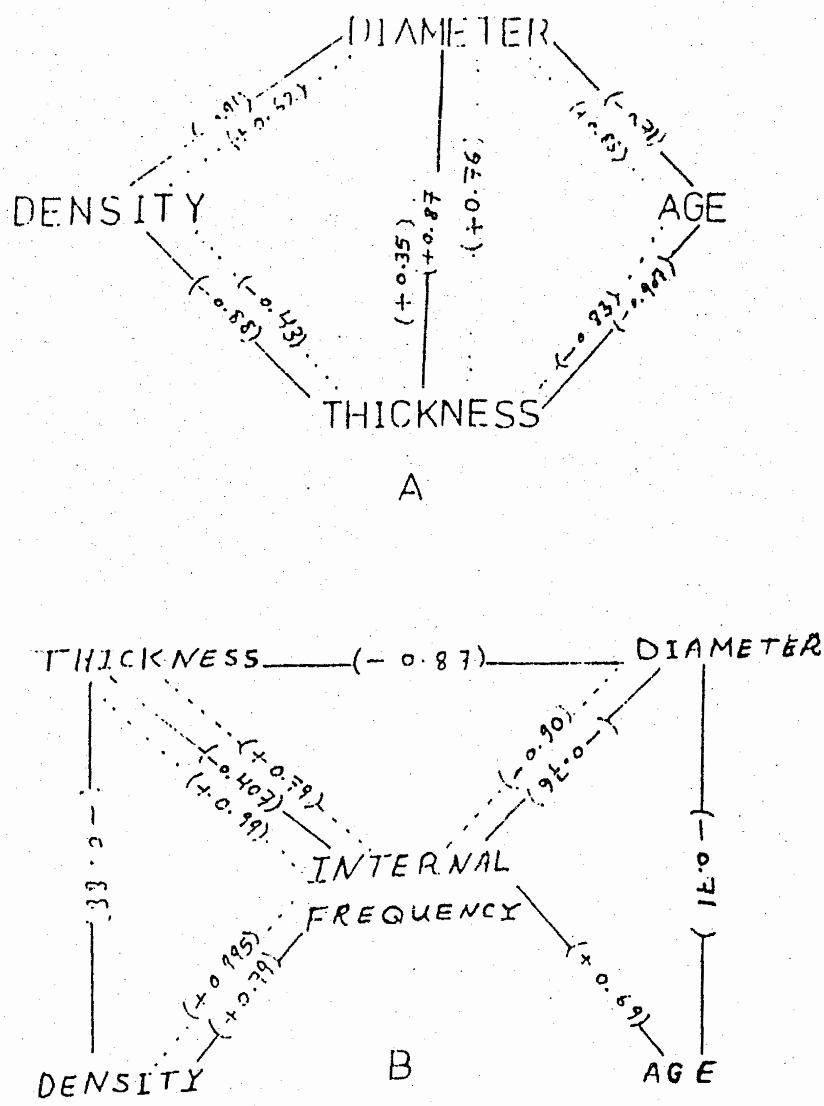

Figure (6)

Multiple corrdlation coeffecients for (6A) morphological relationships and (6B) ultrasonic measuremints of vertebrae. (Continuous line: direct ; dotted line partial).

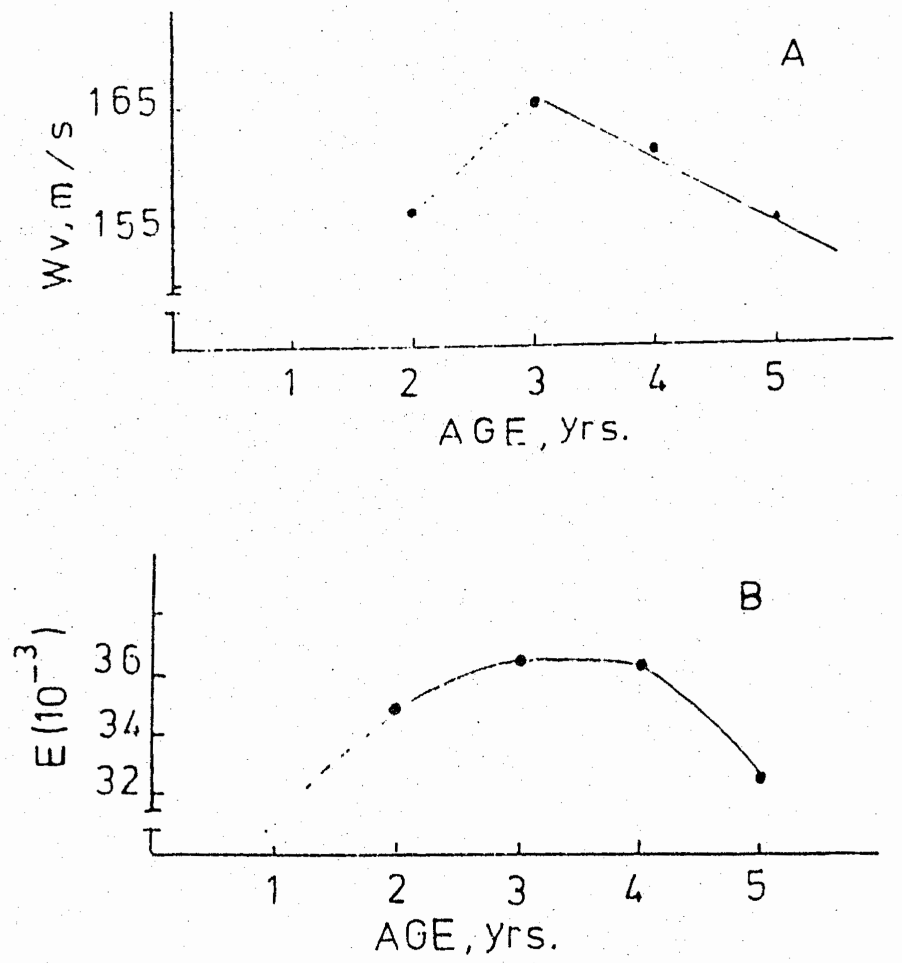

Figure (7)
Variation of (7A) wave velocity (Wv) and (7B) elasticity (E) with age of fish variation .

vary within a species because of differences in growth due to environmental changes due to effect of fishing as indicated by many authors (e.g., Hile 1936. Le Cren 1951, Ricker 1975, Khallaf & Authman 1991). Unfortunately, it is fifficult to trace or relate all of these causes. However, in this study, thickness and has a relatively high correlation coefficient (0.83) when diameter is kept constant . In contrast, age and diameter correlate differently (r = 0,83) when thickness is constant . At the same time , thickness of vertebrae and fish length have a correlation coefficient of 0.799. This can be attributed to fast growth rartes in length among the ecamined samples, i.e., due to selection of fish of large size . This size-selection effect was even greater than the gear selection effect roported by Khallaf and Authman (1991) on the same species. For these reasons, vertebrae thickness is found to have negative effects on the relationship between internal friction and either diameter or density of the vertebrae. Consequently, fish of the same length should be used for evaluation of mechanical properties of their bones, to minimize the effect of variation in the vertebrae thickness. Hamilton et al. 91981) reached similar results but did not indicate which vertebra parameter was decisive.

In the previos method for evaluating mechanical properties of bone by Hamilton *et al* (1981 a). the bone elasticity (Stress aganist strain curve) was used as meaure for such properties by coperession loading of individual vertebrae aligned in an anterior-posterior direction with the copressive force. Elasticity of the fish vertebrae, by use of ultrasonics in

this study, with change in age followed a curve a that can used as a mean of compqrison. However, the presentes results here suggest using the internal friction parameter variation with vertbral diameter (r = 0.90) or density (r = 0.995) when vertebra thickness is constant. Since the vertbrae thickness correlate well with fish length (r = 0.799).

The high correlation coefficient that the wave velocity has with age (r = 0.99) is attributed to that the wave velocity values are dependable upon diameter and thickness of the vertebrae, which in turn are highly correlated with age. Thus, the internal friction paramerter represents a rather simpler method and reduces the work fnneded for calculating clasticity . In this respect either the slope of the regression equation; e.g. between Q^{-1} and Di; and / or the grphical rpesentation of this relationship can be used for comparing the mechanical properties of fish bone for any pupose.

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طريقة جديدة لقياس الخواص المكيانيكية الفقرات الأسماك

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قد تم استخدام الموجات فوق الصوتية لدراسة الخواص الميكانيكية لفقرات أسماك البياض وقد نوقشت عوامل (المقاومة الداخلية، سرعة الموجات والمرونة)، وكذلك العلاقة بين أى من هذه العوامل وخواص الفقرة (مثل القطر ، الكثافة، السمك، العمر وطول السمكة)

وبناء على تقييم احصائى لهذه العوامل فقدتم الوصول إلى أن معامل المقاومة الداخلية يعد أبسط المعايير لإستخدامه فى تقييم الخواص المكيانيكية لفقرات الأسماك.

١ - بحث تم قبوله كمعلق، وقدمه الباحث الأول فى المؤتمر العالمى لمصايد الأسماك بأثينا فى الفترة من ٣ إلى ٨ مايو ١٩٩٢.