# RELATIONSHIP BETWEEN THE MEDULLA AND THE DIAMETER OF FERRET HAIRS

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**Abstract**
The content of this article is a possible explanation of the hair anisotropy, causing the dependence of modulus of elasticity on a hair diameter, which was described in earlier works. The diameter of the medulla part was histologically observed using 27 hairs of 9 different ferrets (*Putorius putorius furo*). The tearing curve was determined for the hairs measured in this way and used to determine material parameters. A linear dependence of medulla thickness on hair diameter was found out, which means a quadratic decrease in the effective cross section of the hair diameter because the modulus of elasticity of the medulla part is lower by two orders than the modulus of elasticity of the cortex. This relationship explains to a considerable extent also the conclusions for the guinea pig (*Cavia porcellus*) hair and the human hairs expressed earlier. At the same time, it is the medulla part what is responsible for the thermal insulation properties of the hair and its description can thus be used when constructing models of materials made of these fibres for their possible industrial applications.

**Key words:** modulus of elasticity, cross section, guinea pig.

## INTRODUCTION

The work focuses on more detailed research on the mechanical properties of animal hairs, especially from the coats of ferrets.

The coat, which is a characteristic of mammals, provides thermal insulation, allows sensory perception, and acts as protection against chemical, physical or microbial damage to the skin (MILLER ET AL., 2012). In the case of animals we can find three types of hairs which produce hair follicles. The primary hair consists of long guard hairs which create the top coat. Each guard hair always grows from its own follicle, but in some cases more hairs can grow from one follicle. The muscles attached to the root of each long hair enable to straighten the hairs. There is also a secondary hair cluster in each guard hair follicle. These secondary hairs include the undercoat. The undercoat function is to provide warmth and protection. Tactile whiskers and eyelashes are the third type of hairs. This type is adjusted to serve as a tactile sensor (ELDREDGE ET AL., 2007).

The hair is embedded in a hair bulb, which is on a fibrous papilla with nourishing blood vessels. The root of the hair is placed in a hair follicle. The hair bulb is connected to a small smooth muscle, which acts as a righting muscle. The hair can be divided into two parts – root and loose hair. The hair root is the part of the hair that is located in the hair follicle under the skin. The loose hair protrudes from the skin (MARTÍNEK, VACEK, 2009).

The hair follicle is composed of five main parts, namely a dermal papilla, which is a group of cells forming a structure right below the follicle, a matrix located around the papilla, which consists of a group of epithelial cells, in which pigment, a hair , and inner and outer cases can be found. The hair itself can be divided into three parts – medulla, cortex and cuticle. The pith (medulla) is the inner part, which consists of longitudinal rows of rectangular cells (PATERSON, 2008). The cortex is the main component of the hair and consists of keratinized cells which are spindle-shaped and flat in shape (MARTÍNEK, VACEK, 2009). Cells containing pigment, melanin, are located here (PATERSON, 2008). Air filled cavities are created in the cells with age and cause the grey to white colour of the hair (MARTÍNEK, VACEK, 2009). The cuticle is the outer layer of the flattened and keratinized cells (PATERSON, 2008). The cells are different in shape and arrangement. They are completely transparent and colourless (have no pigment). They are imbricate and their free edges are oriented to the tip of the hair (MARTÍNEK, VACEK, 2009). The basic motive of this work is to explain why it appears to be decreasing modulus of elasticity with a diameter of hair. An estimate based on the average thickness of the medulla is to be determined dependence of modulus of elasticity on the diameter of the hair.

## MATERIALS AND METHODS

In addition to the hair length and thickness, the mechanical properties of hairs are also dependent on the environment, especially on the temperature and relative humidity, in which the samples are examined.

The samples of hairs were taken from 9 ferrets with different lengths of the hair. The most commonly bred ferrets include ferrets with a standard hair length (i.e. shorthaired), followed by angora ferrets (i.e. longhaired). The third type of hair length, polangora, is created by crossbreeding these two types. Samples were cut by a sharp pair of scissors close to the skin surface in the same area, i.e. on the withers.

The diameter (Fig. 1) of each sample was determined using an optical microscope equipped with a digital camera. The diameter was measured 15 times on the first 3 cm of the sample. Always three hairs taken from each animal examined were measured. The overall diameter for a sample concerned was calculated using the values measured in this way. In the case of most samples, it was possible to measure the internal diameter, i.e. the portion of medulla to the overall hair diameter. We obtained two types of diameter in this way and used them for calculations using the software for processing load curve data obtained from the deformation machine because after the diameters were measured, all hairs examined were clamped in the jaws of a Deform type 2 tearing machine and tightened at a speed of 2 mm/min until the breakage itself of the sample. The Deform type 2 tearing machine used by us is suitable for measuring small and slow changes in biological materials. With the tensometer range of up to 20 N and special jaws for measuring fibres, it enables both to determine a classic tearing curve and to measure relaxation or cyclic loading.

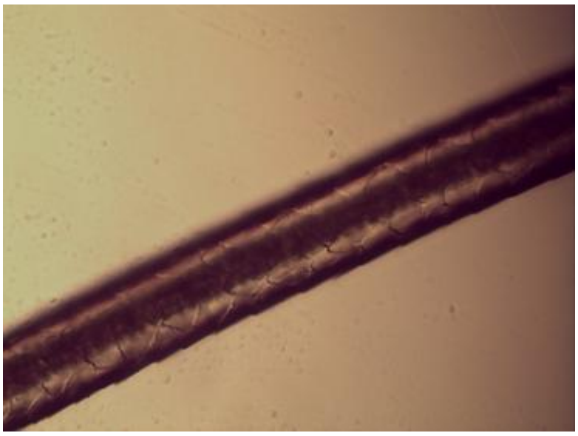

**Fig. 1.** – A photograph of a hair where its lightness, i.e. the portion of the medulla to the overall diameter of the hair, is clearly visible

The makeing photography for the purpose of comparability analyzes DEEDRICK AND KOCH (2004), SKŘONTOVÁ ET AL. (2016).

## RESULTS AND DISCUSSION

The measurement results are clearly arranged in the form of the table and the graphs below.

Tab. 1 gives the average values of the mechanical and material parameters determined using the tearing curves of the ferret hairs. Each of the means or standard deviations was determined using 14 measurements. The table gives both the values calculated classically, with the measured full diameter of the samples, and the values with the reduced diameter, i.e. after deducting the cross section of the medulla part.

**Tab. 1.** – The average values of the mechanical parameters of the ferret hairs determined by us

| | $D$ [µm] | $E$ [MPa] | $\sigma_{0.05}$ [MPa] | $\sigma_{0.2}$ [MPa] | $\sigma_t$ [MPa] | $\sigma_t'$ [MPa] | $\varepsilon_t$ [ ] | $\varepsilon_t'$ [ ] | $W$ [mJ] | $W_A$ [MJ/m$^3$] | $w_e$ [MJ/m$^3$] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $\bar{x}$ | 349 | 64 | 1.00 | 0.91 | 2.25 | 2.76 | 0.22 | 0.20 | 0.47 | 0.37 | 0.012 |
| $\bar{s}_x$ | 67 | 23 | 0.57 | 0.57 | 0.72 | 0.90 | 0.10 | 0.08 | 0.21 | 0.20 | 0.014 |
| $\bar{x}^*$ | 284 | 92 | 1.58 | 1.45 | 3.27 | 3.97 | 0.21 | 0.19 | 0.46 | 0.51 | 0.020 |
| $\bar{s}_{x^*}$ | 43 | 35 | 1.11 | 1.10 | 1.01 | 1.23 | 0.10 | 0.08 | 0.20 | 0.26 | 0.022 |

Glossary to Tab. 1: $\bar{x}$ – arithmetic average of not reduced quantities; $\bar{s}_x$ – average standard deviation of the not reduced quantities; $\bar{x}^*$- arithmetical average of the reduced quantities; $\bar{s}_{x^*}$ - average standard deviation of the reduced quantities; $E'$ [MPa] – actual modulus of elasticity; $\sigma_{0,05}$[MPa] – limit of linearity, or so-called limit of elasticity; $\sigma_{0,2}$ [MPa] – yield point; $\sigma_t$[MPa] – fracture stress; $\sigma_t'$ [MPa] – actual fracture stress; □$_t$ [ ] – elongation; □$_t$΄[ ] – actual relative ultimate elongation; $W$ [mJ] – total mechanical work required for breaking the material; $W_A$ [MJ/m$^3$] – tensile toughness, the amount of energy required for breaking the material related to the initial tensile volume; $w_e$[MJ/m$^3$] – resilience, the amount of energy in a unit of volume of the material concerned loaded with tensile □$_{0.05}$.

Only not reduced values can be found in literature, e.g. ŠIMKOVÁ ET AL. (2013) or SKŘONTOVÁ ET AL. (2015), and if the material parameters are stated in the works, they generally correspond with the data given here. Some parameters such as resilience or elongation, total mechanical work, or tensile toughness are published newly here. Also reduced parameters determined for the hairs of the ferrets with deducted medulla part cannot be found in literature.

Fig. 2 shows the dependence of the modulus of elasticity of the hairs with no correction. The full diameter is therefore used for calculations here as if the entire profile of the hair is exclusively cortex. As a matter of interest, also the power parameter was released when searching for the function; however, it turned out that the experimentally determined dependence is almost perfectly hyperbolic and the power parameter is very close to minus one.

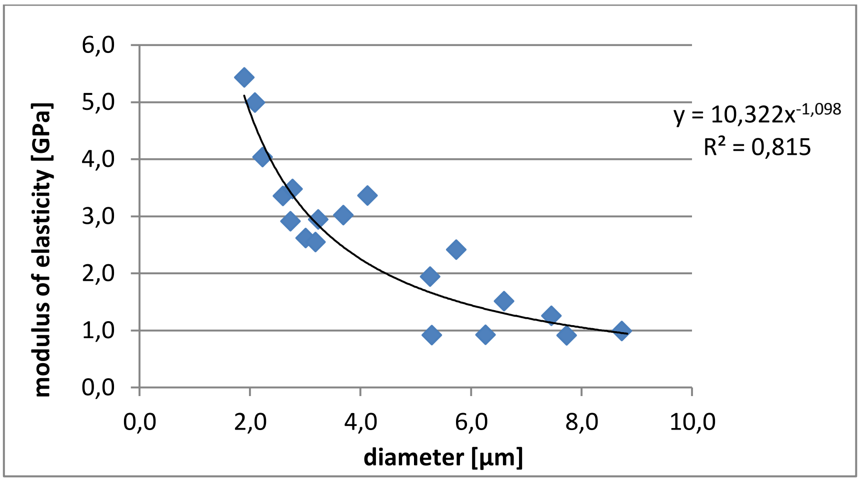


**Fig. 2.** – Dependence of modulus of elasticity on the diameter of individual hairs

As we can see in Fig. 3, a linear equation can be successfully put on the dependence of medulla diameter on hair diameter. Therefore, we can write the formula $m = 0.7\ D - 21$, where $m$ – diameter of the medulla and $D$ – diameter of the hair. This relation enables us to conclude that hairs less than 20 µm thick will not have medulla at all. This result is new and we have not yet succeeded in finding any similar result in literature. However size of medulla depending on age is observed among black people (ABOAGYE ET AL., 2014; LONGIA, 1966).

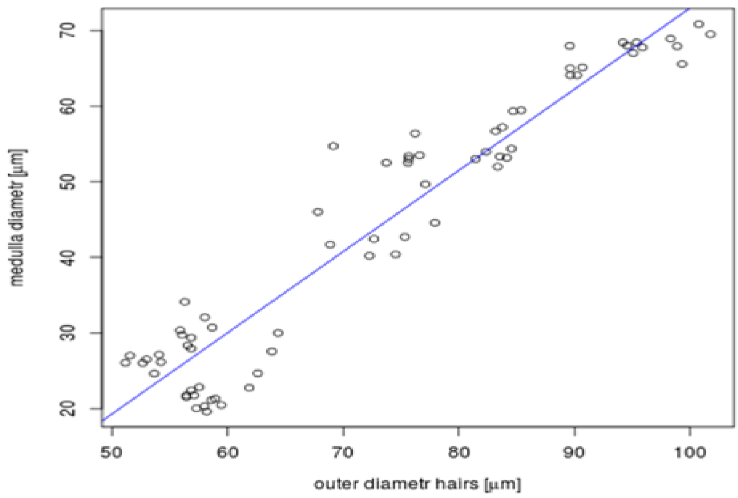


**Fig. 3.** – The graph shows that the dependence of the diameter of the medulla part is approximately proportional to the overall diameter of the medulla ferret hair

The portion of cortex to medulla can be seen in Fig. 4. According to this graph, it is clear that the most frequent values are found in the range of 0.7 to 0.75. This parameter is very specific for various animal species and can be used to identify an animal by hair. This range for ferrets corresponds with HICKS (1977) and LUNGU ET AL. (2007).

Fig. 5 shows the dependence of the determined modulus of elasticity calculated in the usual way, where a hair is regarded as isotropic material despite its great anisotropy, and at the same time the values of the same hairs calculated for the cross section of the cortex only, which is the main support part of the hair. We can see that only a small part of the dependence of module on hair diameter remains unexplained.

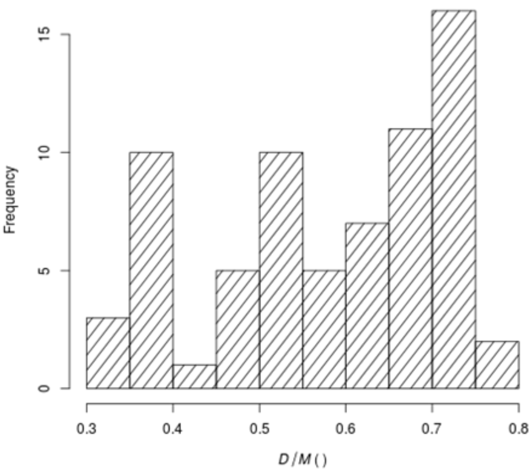


**Fig. 4.** – Histogram with the ratios of the diameters of ferret hairs and the diameters of their medulla parts shows the greatest occurrence in the 65-75 % region, i.e. the medulla diameter is most frequently 65-75 % or 42-56 % of the cross section of the ferret hair.

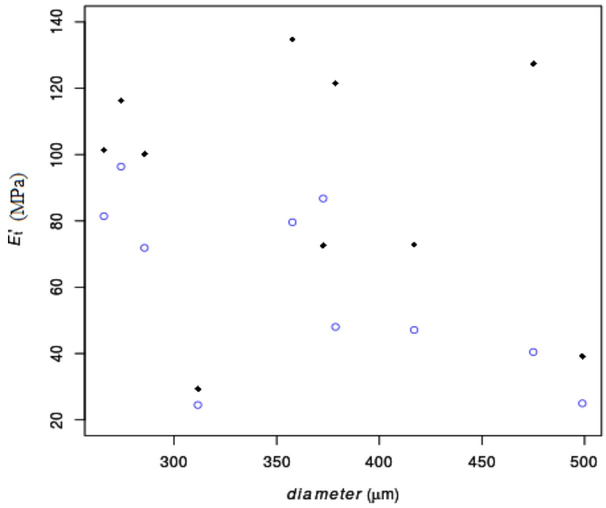


**Fig. 5.** - Dependence of modulus of elasticity ($E_t'$) on hair diameter.

## CONCLUSIONS

Making the current measurement of the medulla part of a hair and determining the tearing curve for the same hairs, we largely succeeded in explaining the previously published dependence of the modulus of elasticity on the cross section of the hair. We succeeded in showing that the dependence of medulla thickness on hair thickness is linear. At the same time, this means that the dependence of the medulla part of the cross section of the hair on the diameter of the hair is quadratic in general. Due to the inclusion of this correction in the calculation of the hair material parameters, the previously determined dependence of the modulus of elasticity on the hair diameter, for example, was explained to a large extent. As the diameter of a hair can be influenced by the breeding method, for example, also the resulting mechanical properties of the coat can be influenced according to these results.

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