APPLICATION OF ZIRCONIUM ALLOYS TO ENDOPROSTHESES
AND OSTEOSYNTHESIS APPLIANCES

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The VT5-1 titanium alloy is presently widely used in this country for manufacturing various osteosynthesis appliances and supporting components of endoprostheses. However, new materials such as zirconium alloys may be more appropriate for these applications for economical reasons, and research in this direction seems expedient. In the present work, we present a comparative analysis for applications in endoprosthetics of three types of alloys: titanium alloy (VT5-1), cobalt alloy (como-chromium), and zirconium alloys.

The mechanical characteristics of these alloys relevant to their use in endoprostheses and osteosynthesis appliances are given in Table 1.

Statistical analysis of endoprostheses which failed in use shows that in the majority of cases a fracture occurs at the endoprosthetic pin. Analysis of the mechanical force pattern in the pin suggests that the pin embedded in a bone can be represented as a bar fixed at one end and loaded with a moment of force at the other end (see Fig. 1).

Flexure of the given system is determined by Eq. (1)

\[ f_0 = \frac{M \cdot l^2}{2 \cdot E \cdot I} \]  \hspace{1cm} (1)

where \( M \) is the acting bending moment, \( l \) the length of the pin, \( E \) the elastic modulus of the material, and \( I \) the inertia moment of the cross section of the pin.

Deformation (flexure) of the pin obviously determines not only its survival but also the extent of its influence on the surrounding bone tissue. Hence, it affects the life of the whole prosthesis. If the flexure is large, the joint will be loosened during its operation, leading to tissue injury and appearance of lysis zones in bones.

Indeed, the calculated values of bending moments in pins are not more than 5-10 kgf/mm², which is less than the yield point of any of the metals used. Therefore, this mechanical characteristic is not a decisive factor for the selection of the material. However, this conclusion assumes that all the materials listed in Table 1 operate within their elastic limits; thus, the elastic modulus becomes a decisive characteristic. According to Eq. (1), the values of flexure and elastic modulus \( E \) are inversely proportional.

The elastic moduli \( E \) of the considered materials are given in Table 1.

Table 1 indicates that the mechanical characteristics of materials based on titanium and zirconium alloys are similar, though como-chromium alloy has distinct advantages. Waldemar Link GmbH (Germany) advertises this product as the most promising.

It should be noted that mechanical characteristics of all the considered materials do not meet the requirements stated by the Richards Medical Company (see Table 1).

Table 1 shows that none of the materials used in practice satisfies the requirements of the Richards Medical Company. Therefore, these requirements seem to be tendentious.

All the considered materials comply with DIN and ISO standards (see Table 1). Thus, the working ability of titanium and zirconium alloys in endoprostheses under static load can be concluded to be similar, como-chromium alloy being slightly advantageous because of its higher elastic modulus.
### TABLE 1. Comparison Between Recommended and Actual Values of Basic Mechanical Characteristics of Alloys for Use in Endoprostheses and Osteosynthesis Appliances

<table>
<thead>
<tr>
<th>Mechanical characteristics of alloy</th>
<th>Recommended values of mechanical characteristics</th>
<th>Actual values of mechanical characteristics of alloys</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>according to specifications of Richards Medical Co. (USA)</td>
<td>according to LSO and DIN standards</td>
</tr>
<tr>
<td>Density, g/cm³</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Elastic modulus E, kgf/mm²</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Ultimate strength σ₁, kgf/mm²</td>
<td>≥98</td>
<td>≥65</td>
</tr>
<tr>
<td>Conditional yield point σ₀.₂, kgf/mm²</td>
<td>≥84</td>
<td>≥45</td>
</tr>
<tr>
<td>Elongation at rupture δ, %</td>
<td>≥10</td>
<td>≥10</td>
</tr>
<tr>
<td>Reduction of area at fracture Υ, %</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

*Data were taken from catalogues of Waldemar Link GmbH (Germany).

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Analysis of the causes of fractures of endoprosthetic pins gives further evidence in favor of the application of titanium and zirconium alloys. Cyclic load (up to $10^4$-$10^5$ cycles per day) during walking, running, etc., is an important feature of prosthesis operation. Pins made of high-strength alloys with low fracture toughness and having mechanical and metallurgical defects shorten the life of the prosthesis. Such early wear can be explained by promoted development of surface defects during cyclic bending of the pin, formation of a crack, and its catastrophic propagation resulting in fracture.

Results of fine fractographic studies of fractures of endoprosthetic pins made of the titanium alloy VT5-1 reveal three basic zones: 1) zone of initial defect (~200 μm); 2) zone of fatigue crack (~1 mm); 3) zone of catastrophic fracture.

Aluminum and tin are added to the VT5-1 alloy to increase its strength. Therefore, this alloy is hardened by the intermetallide mechanism. The technology of prostheses manufacturing allows segregation of coarse intermetallide inclusions, considerably decreasing durability of the material.

Fractographic analysis suggests that the fractures develop from tool marks or mechanical cuts performed across large intermetallide inclusions.