CONTACT SURFACES OF BIG JOINTS – SITES OF THE DEVELOPMENT OF LIMIT STATES AND OTHER CONSIDERATIONS

Vladimír Fuis*, Přemysl Janíček**, Pavel Hlavoň*

This article studies several aspects of problems associated with diseases of big joints. It is an introductory essay to another three articles that focus on solving various biomechanical problems in hip joint. Stress limit states on contact surfaces of the hip joint can be considered as a common denominator of all these problems. General analyses of these states are described in a separate part of this article. Other general analyses concern the complex of problems associated with diseases of big joints. As an illustration (in view of the articles that follow), this article includes a systemic conception of analysis of the applicability of biomechanics in solving therapeutic problems of big joints. As an illustrative example, the hip joint was selected.

Key words : *biomechanics, big joints, contact pressure, failures of joints, surgical treatment of pathological joints*

1. Introduction

In human medicine, problems with big joints often cause orthopedic diseases with varying degree of severity that often prevent patients from doing some of their activities, i.e. functions. Limit state theory asserts that if any of functions of an entity (object or subject) is disabled, such entity reaches its limit state: If an individual is not able to do all his or her everyday functions due to a health disorder, then these limit states can be termed as disease-induced limit states. As diseases are always associated with the pathology of cells, tissues or organs, the term 'pathological limit state' is suggested as an opposite to traumatological limit state that results from trauma, i.e. sudden external intervention in the integrity of an organism without necessary connection with pathological process. Listed in ascending order, such processes can be represented by pathology of organelle, cell, tissue, organ, organ system and a set of organ systems.

There are miscellaneous pathologies of big joints (i.e. hip, knee, elbow, shoulder and ankle joints). Certain big joint diseases can have common cause (e.g. arthrosis of cartilages, infectious inflammation of the joint, cysts, tumors, fractures), other are typical for the particular joint (in hip joint, e.g. developmental dysplasia of the hip, Perthes disease, coxa vara or coxa valga).

Appropriate therapy of big joint disorders, of course, depends on the type of the disease. However, as in many other diseases, there are two basic therapeutic approaches to big

* Ing. V. Fuis, Ph.D., Ing. P. Hlavoň, Ph.D., Centre of Mechatronics – Institute of Thermomechanics AS CR and Institute of Solid Mechanics, Mechatronics and Biomechanics, Faculty of Mechanical Engineering, Brno University of Technology

** prof. Ing. P. Janíček, DrSc., Institute of Solid Mechanics, Mechatronics and Biomechanics, Faculty of Mechanical Engineering, Brno University of Technology

joint diseases, i.e. non-surgical (pharmacologic) and surgical. The latter can be significantly supported by cognitive and clinical orthopedic biomechanics [1].

The application scope of biomechanics in practical clinical orthopedics of joints should be defined systematically as follows: The set of typical diseases of each big joint should be drawn up and the particular therapeutic approach to each disease should be analyzed. Then it should be decided whether biomechanics will be useful for such therapy. In other words, it has to be defined, when the solution of a biomechanical problem can be useful for the solution of the particular clinical orthopedic problem. In this article, such approach is outlined for the hip joint.

As analyzed below, big joints frequently show limit states that are caused by problems on their contact surfaces. This is true both for biological joints and their partial or total replacements (these problems are reflected also in the three articles that are to come). Problem situations associated with big joint diseases require solving a great many miscellaneous aspects that include medical, bioengineering, subjective and social problems. These issues are described in the final part of this article.

2. The incidence of basic diseases of the hip joint – possibilities of the utilization of biomechanics

Hip joint pathologies and the possibilities of utilization of biomechanics in therapies of various hip joint diseases is a theme that could be described on hundreds of pages. However, in this article we will have to make do with only two pages that should contain all important hip joint diseases. As there are a great number of such diseases which, furthermore, can occur in almost every period of human life, this is really a hard task. Many people are born with hip joint diseases (around 10 % of population); osteoarthritic diseases usually trouble patients in their retirement age. And there are many other hip joint disorders that affect people between these two periods of life. Although hip joint diseases are not associated with high mortality, they belong to highly 'expensive diseases.

Basic hip joint diseases occurring during patient's life are listed and briefly characterized in Fig. 1. The incidence rates of individual diseases are indicated by the thickness of boxes that are detailed in the subsequent text. There are the following groups of diseases:

1. **Developmental dysplasia of the hip (also known as congenital hip dislocation)** is a set of disorders observed in newborn children. The disorders are characterized by morphological and topological changes of the future hip joint elements and include dysplasia (large acetabular roof angle), subluxation and luxation (lateral shift of the core of femoral head). These are prearthrotic diseases, as they result in osteoarthrosis (dashed line), if untreated. As such, they must not be underestimated in childhood and require consistent therapy.
   Biomechanical studies, if accepted and realized by clinical practice, can help solve problems with untreated prearthrotic diseases that are characterized by pathological changes in hip joint geometry. Biomechanical studies determine stress-strain states of the joint elements and contact pressures on contact joint surfaces for various types of osteotomies used as a therapy of various pathological geometries of the joint. The solution of such problem is illustrated in article [3]. If biomechanical studies were realized systemically, their computerized results could support surgeons when deciding what type of osteotomy

should be selected. Biomechanical studies of this kind should be considered as activities of basic research, though they could later become the basis for application.

2. **Perthes disease** is a disease of unknown cause affecting mainly boys between 2 and 10 years of age. If untreated, it results in extensive deformities of femoral head. As such, Perthes disease is a prearthrotic disease.
   Orthopedic biomechanics can be used in the same way as in dysplasia.
3. **Coxa vara adolescentium** is caused by degradation of growth plate between femoral neck and head. As a result, femoral head slips downwards and backwards, which reduces the angle made by the neck and shaft of the femur (the so called cephalo-cervico-diaphyseal angle) leading to coxa vara.
4. ***Osteochondritis dissecans*** is a circumscribed necrosis of subchondral bone observed not only in the hip. Typically, a sclerotic margin is developed around necrotic focus. Later on, necrotic fragments ('joint mice') start to fall off and block movements of the joint.
5. **Ischemic necrosis of adult femoral head** can be caused by anything that disturbs, restricts or blocks vascular supply of bone tissues in such a manner that it induces ischemia and subsequent necrosis of the tissue. This condition is usually caused by traumas, fractures, arterial embolization, radiotherapy, dialysis, corticoid therapy, surgical interventions, smoking, alcoholism, inadequate sport activities, benign or malignant tumors etc. Inappropriate therapy can result in the head deformation, sclerotization of subchondral bone, formation of subchondral cysts and secondary coxarthrosis. This disease can occur in any period of life.
6. **Osteoarthrosis of the hip joint (*coxarthrosis*)** is a degenerative disease of articular cartilages accompanied with significant pathological changes of femoral head and acetabulum (sclerosis or even necrosis of subchondral bone, formation of osteophytes and cysts, loss of cartilages, head deformation, or development of ankylosis). Untreated coxarthrosis usually leads to total hip replacement.
   In coxarthrosis, biomechanics has been used for the longest time (1), most extensively (2) and in the most versatile manner (3).

   (1) Clinical conditions for total hip arthroplasty have been established as early as in 1950s. Orthopedic surgery thus started modern times of biomechanics. In 1950, Gonet realized cervicocapital replacement with metal shaft and plastic head. McKee introduced total hip replacement with metal socket and head in 1953. In 1963, Charnley presented total hip replacement with metal shaft and head and the socket made of low-pressure high-molecular polyethylene. During further development of hip replacements, separated ceramic heads started to be used (first, aluminum oxide Al_2O_3, later also zirconic oxide ZrO_2 were used).

   (2) Total hip replacements represent the greatest number of all total arthroplasties. There are at least two reasons of this fact: The hip joint is the most loaded joint in a human body while its geometry is very simple. Total replacement of the hip joint can be therefore uncomplicated as well.

   (3) As far as the hip join is concerned, resurfacing procedures or total replacements can solve various problems that can be grouped as follows:

   + *Constructive problems* include designs of partial or total replacements with different topologies, material structures of acetabulum (multi-layer acetabulum from various materials), material combinations of heads and sockets – all this with respect to possible limit states (the endoprosthesis itself, adjacent bones, wear of contact surfaces). A constructive problem is illustrated by the design of elbow joint replacement [4].

+ *Cognitive problems* include determination of deformation and tension states in endoprosthesis and adjacent bones elements: for various types of resurfacing and total replacements, various sizes of collodiaphyseal angles, various acetabulum position, characteristics of materials of contact surfaces, effect of inaccuracies on reliability of endoprosthesis elements etc.
+ *Interaction problems* include solutions of mechanical interactions between endoprosthesis materials and adjacent tissues, various types of cements of cemented endoprostheses and contacting tissues etc.
+ *Inversion problems* occur when different limit states were reached and their cause should be found. Possible limit states include impaired cohesion of endoprosthesis elements (stem, head, and acetabulum), necrosis or atrophy of adjacent bone tissue, loosening of endoprosthesis elements (stem, acetabulum), development of metal- or polyethylene-induced diseases.

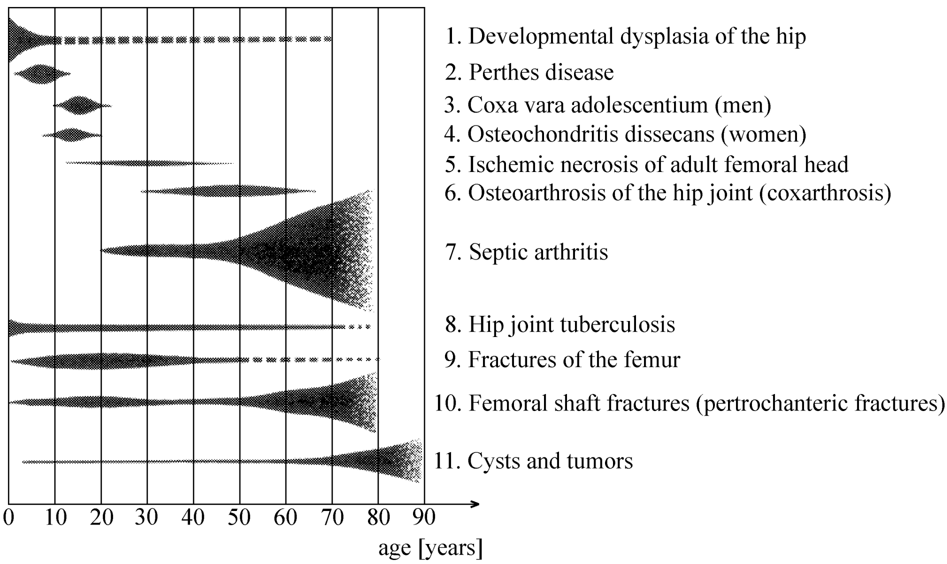

Fig.1: Periods and rates of the incidence of hip joint diseases [2]

7. **Septic arthritis**: The joint is infiltrated by infection from an infectious focus, mostly via blood. The most frequent pathogen is *Staphylococcus aureus*; in newborns it is *Streptococcus agalactiae* that asymptomatically colonizes various mucosas. The infection causes painful inflammatory processes that restrict the function of the joint and induce exudate, erythema, fever etc. The inflammation can lead even to structural changes of the cartilage and subchondral bone. The disease is observed mainly in children (children under 2 years of age represent one half of patients, with boys being affected twice as often as girls).
8. **Hip joint tuberculosis** is caused by *Mycobacterium tuberculosis*, mostly infiltrating the organism via airways. Tuberculosis infection usually disseminates through the body

without symptoms. Tuberculosis can be found in any part of the skeleton, with the spine (50 %) and hip joint (ca 10 %) being the most affected parts. During healing, ankylosis often develops, manifested by adhesion of the head and acetabulum leading to the stiffness of the joint.

9. **Fractures of the femur**: Fractures in the area of femoral diaphysis with various localization and orientation.
   Biomechanics helps optimize the structure and shape of marrow nails.
10. **Femoral shaft fractures**: Fractures are observed in the area of the head, neck and trochanteric crest and may result in necrosis.
    Biomechanics helps optimize the structure and shape of sliding nails.
11. **Cysts and tumors**: Juvenile bone cyst occurs in children and adolescents. Giant-cell tumor of bone is another serious disease that occurs after the end of skeleton growth, i.e. between 15 and 35 years of age. Furthermore, chondrosarcoma and metastases from various primary centers have been reported.
    Tumorous hip joint diseases are treated using dedicated total replacements.

3. Contact surfaces of big joints – sites of the development of potential limit states

Contact surfaces of big joints (especially hip, knee and shoulder joints), irrespective of whether they are biological joints or partial or total replacements, are sources of possible limit states.

In biological joint, contact objects are represented by cartilages that can show degenerative changes of various causes (overload, hemophilia, ochronosis etc.). Osteoarthrosis develops and may cause dysfunction of the joint representing the limit state. Partial or total joint replacement is a boundary solution of such limit state.

Unlike contact surfaces of biological joints, the surfaces of joint replacements are made of technical materials. Nevertheless, they remain the sites of the development of limit states of the joint, though the character of these states is different. Such limit states can be associated with high weight wear rate inducing adverse changes in articular bones and leading to the dysfunction of the ‘artificial joint’ (e.g. due to its loosening). If contact elements are made of brittle materials (e.g. ceramic materials), brittle failure limit states can occur. In both cases, deformation and tension states of endoprosthesis elements must be understood. In wear limit states, the rate of wear is significantly affected by the area of actual contact surfaces, distribution of contact pressure over these surfaces and contact pressure values.

Specific contact problem arises in the total hip replacement that has the head put on the shaft cone. In one structural design of this kind, limit states of brittle failure occurred in a ceramic head. Experimental and computational modeling showed that head damages were caused by variation of the shape (taper and ovality) of internal head cone and external shaft cone, both at macro and micro levels. These problems are described in article [6].

The abovementioned aspects should be thoroughly investigated in terms of deformation and tension states of big joints, namely for their physiological states (they work as benchmarking standards), pathological states (being induced by many diseases) and partial or total replacements. Intensive research effort should also focus on causes of limit states in biological and ‘artificial’ joints.

4. Problems of big joint diseases

The considerations below are based on a non-standard situation of an individual who has symptoms of a big joint disease. Such situation triggers other difficulties that induce many miscellaneous problems, primarily medical, that can be solved with the support of bioengineering methods. If the diagnosis confirms the existence of such non-standard situation, various personal and social consequences leading to many considerable subjective and social problems occur. These problems comprise a system of interconnected heterogeneous problems as showed in Fig. 2.

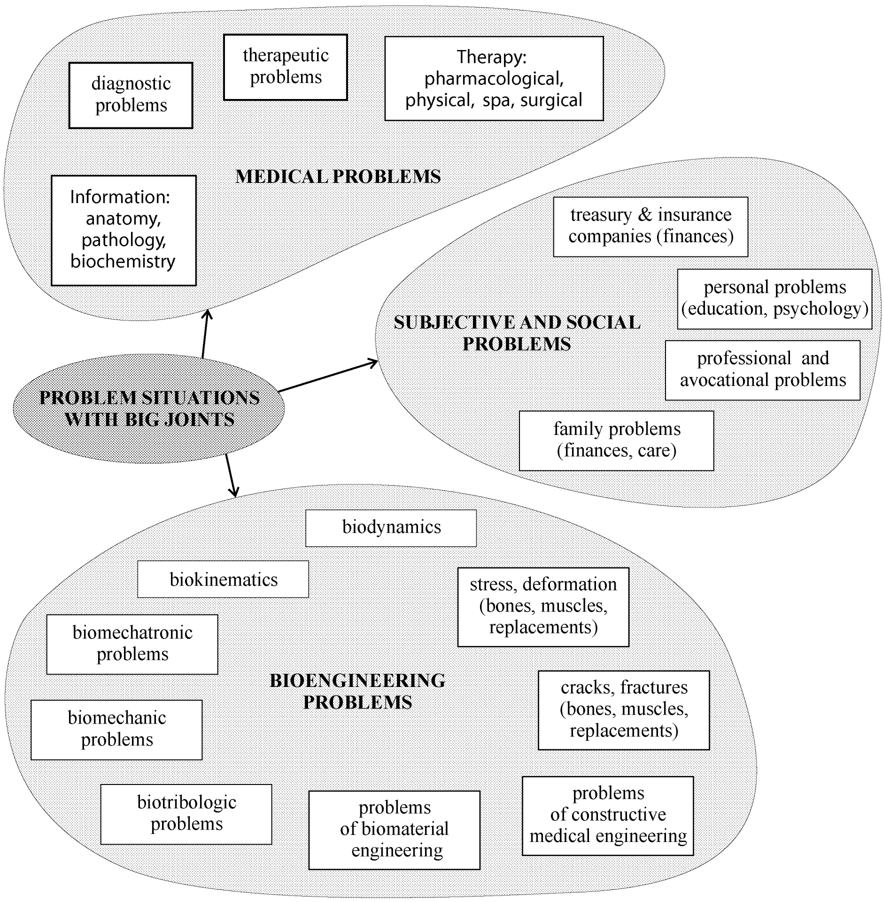

Fig.2: The complex of problems to be taken into account when solving situations associated with symptoms of big joint diseases

One group of problems represents medical, mainly diagnostic, problems that are solved using various anatomical, physiological, pathological, and biochemical data about a given big joint. Diagnostics and therapy depends primarily on the patient's age. Of course, type of disease in newborns is not evaluated based on medical history or subjective reflection of the problem, but clinical examination and sonography or radiography (e.g. triple screen test is used in hip joint diseases). In adult patients, diagnosis is performed based on medical history, self-perception, radiography, computerized tomography and magnetic resonance imaging. Therapy is selected according to the severity and advanced state of the disease.

Possible therapeutic approaches include pharmacological treatment, physical and spa therapy, surgical intervention (an appropriate type of osteotomy) or application of various types of joint replacements.

Nowadays, many medical therapeutic problems are typically solved using various bioengineering approaches, most often biomechanics. This is particularly true for human big joints. Orthopedic clinical practice uses bioengineering knowledge above all for surgical approaches based on osteotomy or the implantation of joint replacements.

Big joint diseases in humans may trigger also subjective or social problems. Subjective problems include pain, limitation of professional or avocational activities, and possible family problems due to the requirement of increased care and reduced financial income. Objective problems include financial load of insurance companies and the treasury that is considerable.

5. Possibilities of solving biomechanical problems

In the previous paragraph, it has been described that big joint diseases entail not only trauma of the individual, but also serious social and economic problems. That is why clinical orthopedics pays great attention to big joint diseases. It has also been mentioned (as well as it will be documented in articles that are to follow) that human orthopedic biomechanics can significantly help solve clinical problems with big joints. This field of research is fostered in biomechanical centers. All such centers in the Czech Republic work at universities and have predominantly technical orientation. However, the centers have serious problems with raising funds for biomechanical research. One of the possibilities is to apply Czech and foreign (European) grant agencies for research grants. Unfortunately, the Czech Science Foundation (GAČR, Grantová agentura České republiky) does not have an independent bioengineering division that would cover requirements of biomechanics. Researchers in the field of biomechanics are therefore in difficult situation, as they are not clear where to apply for their grant projects. Another problem lies in the fact that GAČR prefers basic research projects. Researchers thus have to prove that their projects have the character of basic research.

The suggested problems are detailed in article [5] that proposes changes of the status quo in order to remove biomechanics from the periphery of the Czech research and development policy.

6. Conclusion

This article is not a monograph and does not want to summarize the solution of the particular biomechanical problem. It is an introductory essay to another three monothematic articles on the solution of problems with big joints. At the same time, the authors wanted to outline a general procedure of recognition of big joint diseases that can be solved with the help of biomechanics and pinpoint multifactorial significance of these diseases. The article also draws attention to difficulties of researchers in the field of biomechanics (and generally all bioengineering fields) with raising funds for investigation of technical bioengineering problems.

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