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SCAFFOLDS IN KNEE JOINT MENISCUS ENGINEERING

Abstract

Introduction and aims: In the knee joint are located two menisci, which play an essential role in the preservation of chondral surfaces and assurance of knee stability. Due to their activity during knee movement, they are strongly exposed to injury not only during professional sport training, but during normal, active life as well. In case of complex degeneration of the meniscal tissue, the regeneration help is needed. This help is provided by polyurethane or collagen meniscus scaffolds.
Material and methods: The model of the right knee joint has been designed to in order to investigate the distribution of reduced stresses. *The NASTRAN* application has been used for calculations.
Results: The distribution of the reduced stresses in the right knee joint model are presented in the article.
Conclusion: Scaffold is a matrix that is designed to replace the damaged meniscal tissue. It is useful in case of complex tears, for which assessment of biomechanical function restoration after sewing is negative.

Keywords: Anatomical meniscus, tissue engineering, scaffold, meniscus implant.
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SKAFOLDY W INŻYNIERII ŁĄKOTKI STAWU KOLANOWEGO

Streszczenie

Wstęp i cele: *W stawie kolanowym znajdują się dwie łąkotki, które odgrywają istotną rolę w zachowaniu powierzchni chrzęstnych oraz zapewniają stabilność kolana. Ze względu na ich aktywność podczas ruchu stawu kolanowego, są silnie narażone na uszkodzenia, nie tylko w profesjonalnym treningu sportowym, ale również w normalnym, aktywnym życiu. W przypadku złożonych uszkodzeń tkanki łąkotki pożądana jest jej regeneracja, która jest wspomagana przez poliuretanowe lub kolagenowe skafoldy łąkotki.*
Materiał i metody: *W celu wykonania badań skonstruowano model prawego stawu kolanowego. Aby otrzymać wartości naprężeń zredukowanych w teście zastosowano program numeryczny NASTRAN.*
Wyniki: *W pracy przedstawiono rozkłady naprężeń zredukowanych w modelu prawego stawu kolanowego.*
Wniosek: *Skafold jest matrycą, która ma zastąpić uszkodzoną tkankę współpracujących powierzchni kolana. Ta metoda regeneracji jest szczególnie użyteczna w przypadkach ujemnej oceny możliwości przywrócenia biomechanicznych funkcji łąkotki po zszyciu.*

Słowa kluczowe: *Anatomia łąkotki, inżynieria tkankowa, skafold, implant łąkotki.*
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1. Mechanism of meniscus tear

The knee joint menisci are two C-shaped fibrocartilage structures that deal with substantial number of responsibilities in tough conditions inside the joint capsule. Besides proprioception, lubrication, shock absorption, cartilage layer protection, menisci are liable for load distribution and determine the limits of maximal knee extension and flexion [6], [18], [25].

To cover those tasks menisci can be permanently fixed to neither femur nor tibia. However, secure connection is provided by ligaments. Meniscotibialia anterius and posterius ligaments anchor medial meniscus to tibia, while meniscofemoralia anterius and posterius ligaments fix lateral meniscus to femoral condyles. In addition to this, medial meniscus is connected to medial collateral ligament (Fig. 1a) [2], [3], [6], [22], [25].

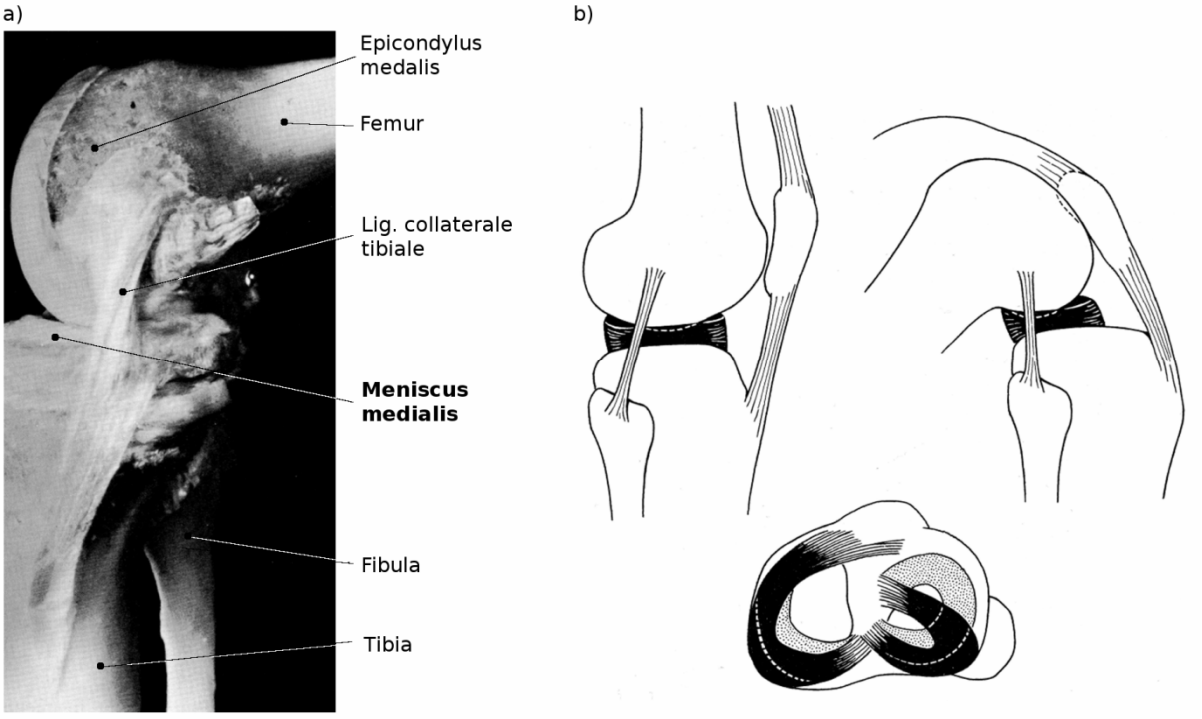

Fig. 1. Knee meniscus: (a) an anatomic preparation,
(b) the range of menisci displacement while flexion [13]

Those solid but flexible constrains allow menisci to actively participate in the knee motion. They move backward during knee flexion and come forward again while extension (Fig. 1b). Moreover, the menisci make the rotational knee movement possible [11]. At the time of knee rotation one meniscus moves ahead and the other one back with sliding range of more than one centimetre [3], [15], [22].

During brisk motion, like swift extension or rapid rotation with concurrent flexion menisci can fail to follow. As a result, a knee becomes painful, swallowed and usually locked by meniscus or menisci that get stuck. It is a very common trauma associated with contact sports, like football, volleyball, hockey or skiing [10], [11], [25], [27].

The lesion area and type depends on knee movement mechanism that causes the injury. The tear, that is a direct corollary of the injury, is generally a simple one. The degeneration progress leads to complex or displaced tears like flap or bucket-handle (Fig. 2). As a result, the interface of femoral condyles and tibial plateau surfaces is inaccurate and escalates articular cartilage deterioration that is followed by osteoarthritis [6], [10].

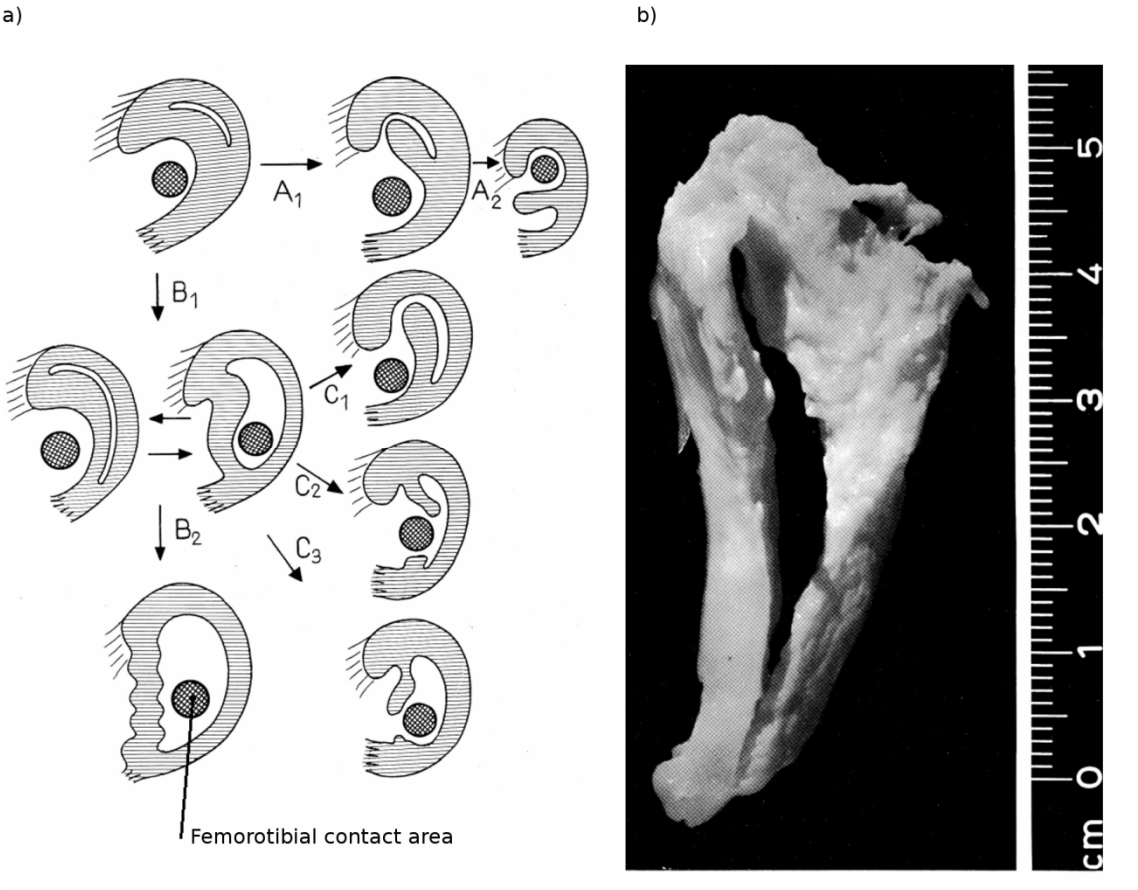

Fig. 2 Meniscal lesions: (a) progress of a simple longitudinal tear (left upper corner) to a complex one: line A to flap tear, line B to bucket-handle, line B-C to ruptured bucket-handle, (b) specimen of meniscus with bucket-handle lesion [13]

While meniscal lesion is immediately diagnosed and appears in the outer rim zone, where environment is vascular with high healing potential, the physical therapy has a high success rate in regeneration [8], [25], [26]. Another treatment option for tears, that occurs in the vascular, so called “red-red” zone, is sewing [9], 12], [20], [24], [25]. However, it is helpless in the face of degenerative lesions without technical possibility for reconstruction.

2. Scaffold application

Scaffold is a matrix that is designed to replace the damaged tissue. It is useful in case of complex tears, for which assessment of biomechanical function restoration after sewing is negative.

During an arthroscopic surgery, the degenerated part of menisci is debrided, like during meniscectomy. Range of removed tissue is extended to vascular rim to cause blood flow into scaffold (Fig. 3). As soon as wound is prepared, it is measured and scaffold is cut to the size to fit any personal case. Then implant is sutured to the outer meniscal rim. Highly porous structure supports migration of cartilage repair cells and nutrients. The newly created tissue grows into scaffold and continuously replaces it during its biodegradation. It has been noticed that after about half a year an immature collagen converts into dense fibrocartilage [4], [21], [23], [27].

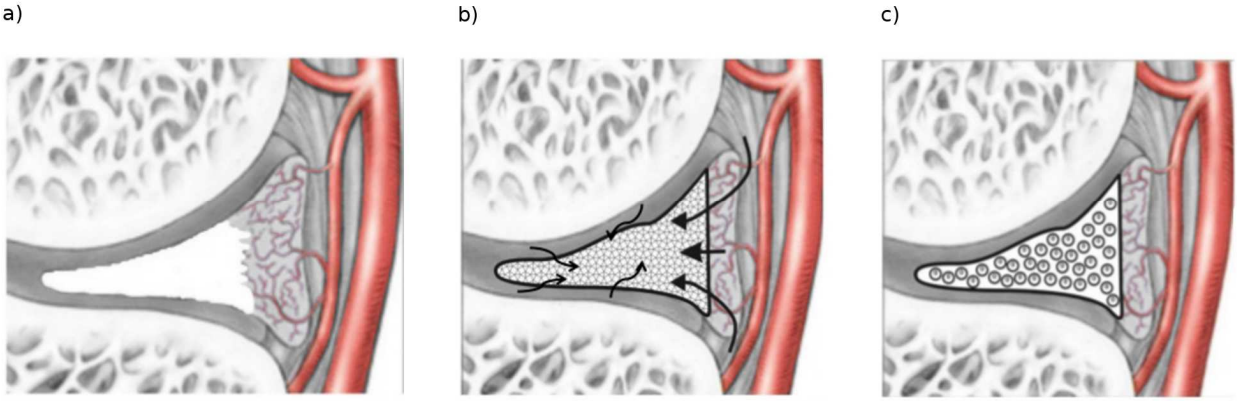

Fig. 3 Scaffold concept: (a) the damaged tissue is removed (white section), (b) scaffold is sutured into the meniscus and tissue regeneration occurs through vascular in growth and cellular infiltration from the synovium and meniscal rim, (c) rise of regenerated functional tissue with meniscus-like characteristic [1]

The scaffold is only a template, that supports regeneration, not a substitute for an anatomical meniscus. There are two types of scaffolds that are applied nowadays in clinical trials: polyurethane and collagen.

The Actifit [1] is the aliphatic polyurethane scaffold that is characterized by a honeycomb structure (Fig. 4). It contains two types of segments: soft and urethane. Soft segments are about four fifth of the polymer. They are responsible for flexibility and contain poly (ε-caprolactone). The urethane segments, that contain 1-4-butanediisocyanate and 1-4-butanediol, are dedicated to ensure strength.

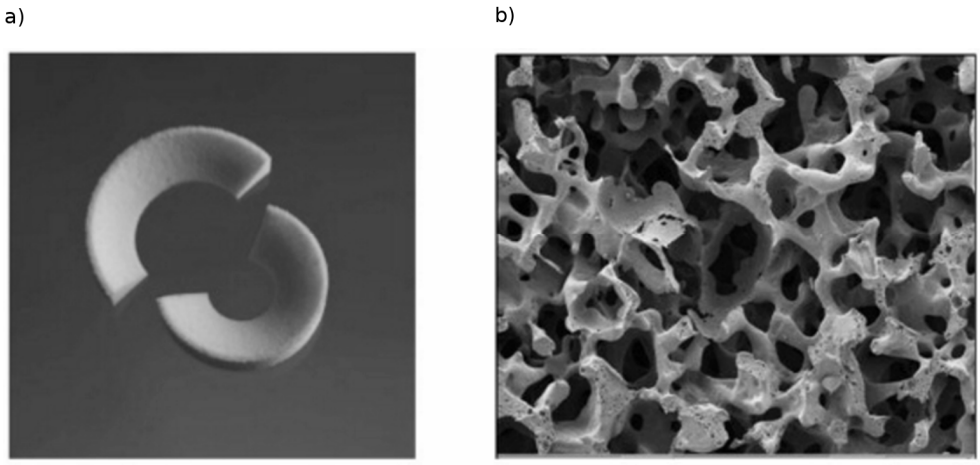

Fig. 4 Actifit aliphatic polyurethane scaffold: (a) variants for medial and lateral meniscus, (b) porosity of the structure [1]

At Ghent University Hospital [23] was conducted a study concerning Actifit. More than fifty patients were observed by two years after replacement of a damaged part of menisci by the polyurethane scaffold. According to the observation, there was no serious adverse events, and cartilage status was deteriorated only for less than 10% of total patients.

Fifty four patients in six European centres [4] were involved in one more polyurethane scaffold study. This research comprises only lateral menisci. The two years long follow-up revealed constant improvement and very low failure rate, since about 5% of patients were classified for surgery revision.

The second meniscus scaffold type is a collagen one (Fig. 5). Type I collagen fibres are purified from bovine Achilles tendon and then chemically treated to keep only collagenous sub-

stances [21,27]. The resultant structure has the density at 0.2 g/cm3 with tolerance of ± 0.02, and pore in size between 75 and 400 μm.

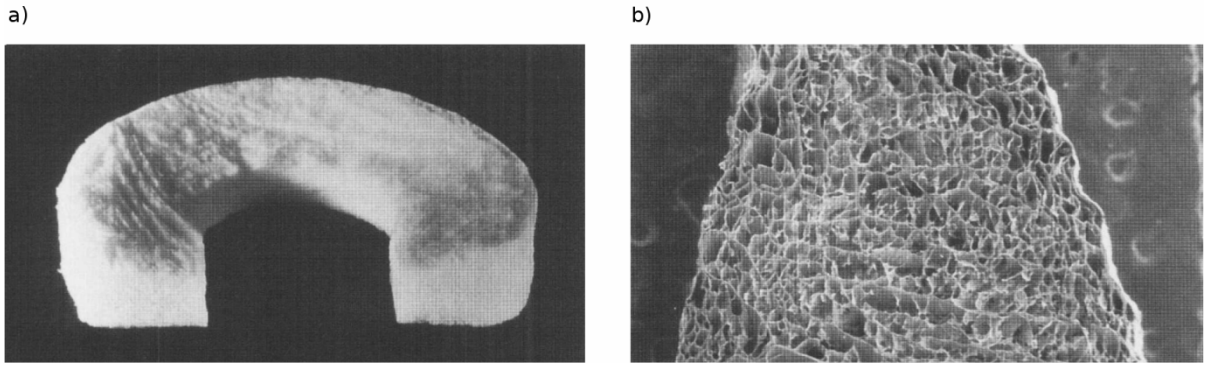

Fig. 5 Collagen meniscal implant: (a) photograph,
(b) scanning electron micrograph of a cross section [20]

Stone, Steadman, Rodkey and Li [21] were the first who undertook the clinical trial of collagen meniscus scaffold implantation. The inclusion condition "irreparable tear of meniscal cartilage or major loss of meniscal cartilage in stable or stabilized knee" was met by nine patients. During three years of observation, it was proved that collagen scaffold promoted tissue regeneration not only in outer, vascular rim, but in avascular zone as well. Radiograph examination showed stable state of the joint space.

Another study was performed in Bologna [27], where research team treated thirty three patients with collagen implants or meniscectomy. After ten years follow-up joint space was not significantly narrowed within the implanted patients group, in contrast to the meniscectomy group. In addition to this, pain was reduced and general health was improved in the implant group according to patients declaration.

3. Menisci role in the knee joint - summary

The time, when menisci were said to be a redundant tissue, is over. They are no longer removed at any single pain of the knee. Their importance in load distribution was proven during numerous researches. A.M. Ryniewicz [18] analysed the multilayer knee model. The maximal displacements and stresses in the knee joint were noted in menisci (Fig. 6), that proven their essential role in shock absorption and load distribution.

The damaged meniscus is not able to cover its responsible tasks. Cartilage layer is not protected any more. Because cartilage layer is not designed to carry over such load, it is slowly damaged, becomes more and more rough. When the roughness increases, cartilage starts to develop into fractures. Bone tissue becomes uncovered, then hardens, and rebuilds [7]. Bone spurs are created, and separated cartilage particles cause inflammation. This disease is called osteoarthritis.

At early stages osteoarthritis can be recognized by radiological methods like magnetic resonance imaging [5], [16], [17], [19], but no symptoms occur. Groniowski and Krus [7] claim, that every tenth man in age above forty years suffers clinical symptoms, it means pain, joint stiffness and deformation, but in about 90% of population osteoarthritis is recognized radiologically. No treatment method is developed so far, that is why prevention of the knee joint menisci is so important. Polyurethane and collagen scaffolds allow those, who were treated with meniscectomy and doomed to osteoarthritis, a chance for active life and even continuity of their professional sport carrier [1].

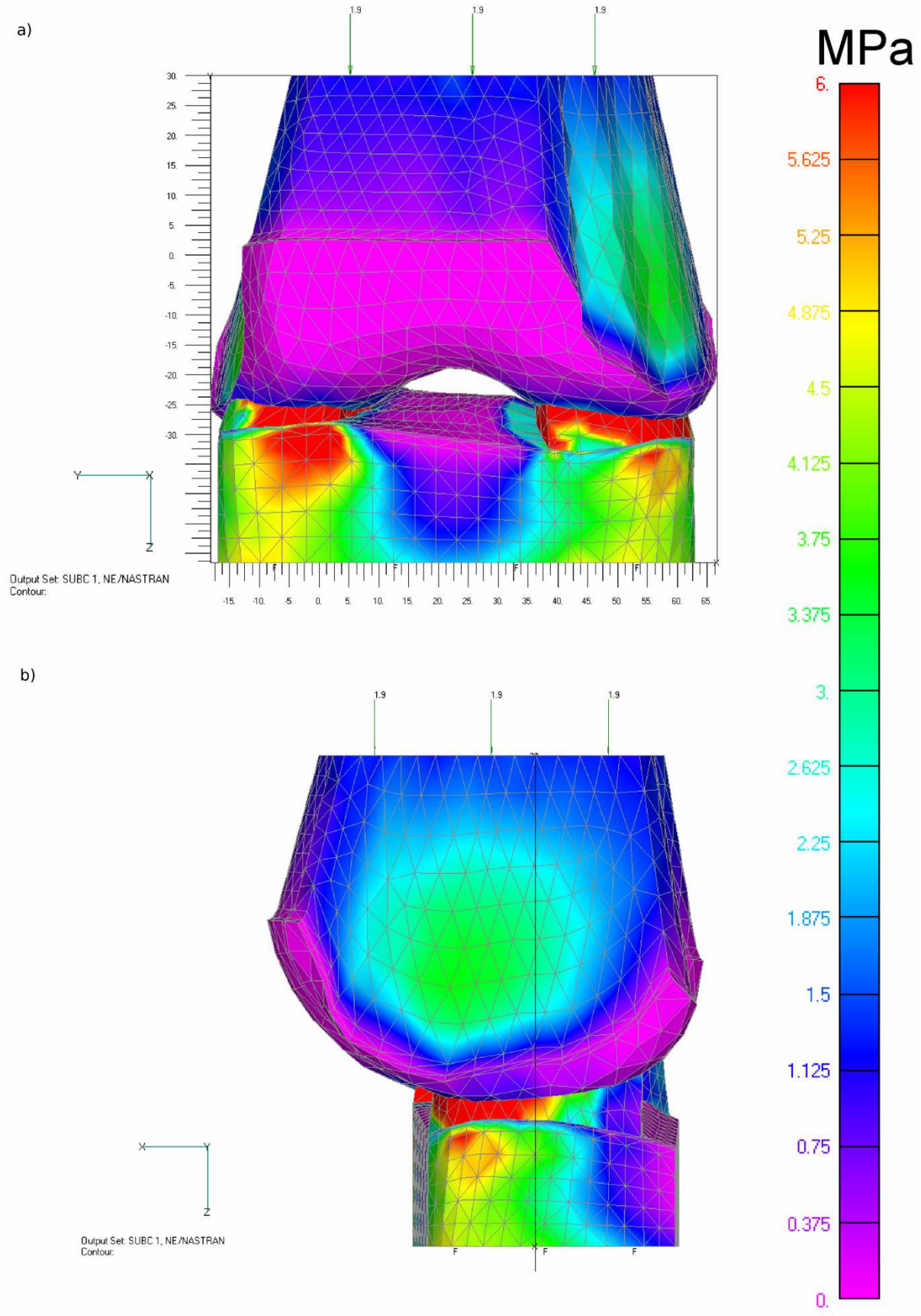

Fig. 6 Distribution of the reduced stresses in the right joint model:
(a) anterior view, (b) lateral view from the medial aspect [18]

4. Conclusions

- In the knee joint are located two menisci, which play an essential role in the preservation of chondral surfaces and assurance of knee stability. Due to their activity during knee movement, they are strongly exposed to injury not only during professional sport training, but during normal, active life as well.
- In case of complex degeneration of the meniscal tissue, the regeneration help is needed. This help is provided by polyurethane or collagen meniscus scaffolds.

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