Soft-tissue damage during total knee arthroplasty Focus on tourniquet-induced metabolic and ionic muscle impairment

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ABSTRACT

Purpose: Advantages of tourniquet use in TKA include benefits for surgeons and patients, varying from a bloodless operation site to a reduced intervention time. The time under ischemia and the reperfusion period are crucial phases for affected soft-tissue, most commonly the extensor mechanism.

Case reports: documented its impact on soft-tissue, ranging from necrotic muscle damage to systemic inflammation. Recently, research regarding tourniquet application patterns discuss clinical outcome parameters in the context of soft-tissue damage, excluding the underlying pathophysiological mechanisms.

Methods: This review summarizes the molecular aspects of soft-tissue damage occurring during tourniquet application in TKA with special focus on ischemia/reperfusion injury. Recent meta-analyses and original trials were reviewed for data on muscle damage and are presented.

Conclusion: Although underlying pathomechanisms are well known and presented, clinical orthopedic research has so far not addressed this issue. In context of physical training, positive effects regarding postoperative recovery might be possible if more attention is paid to prepare involved muscle preoperatively to TKA (prehabilitation).

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1. Introduction

Knee arthroplasty is a well-established surgical care for patients with knee arthritis and has been extensively advanced since the first total knee arthroplasties (TKA) in the 1960ies. Yearly implantation rates increased over the last years in Germany (>134 implantations per 100.000 inhabitants),¹ mostly due to good restoration and enhancements in patient's quality of life. In the United States 650.000 primary TKAs were performed in 2008, summarizing to costs of \$9 billion in total. The expected increase in the number of annual TKA surgeries is estimated to be around 3.48 million by 2030.² Still, despite substantial advances in surgical technique and implant technology, only 72–86% of patients are satisfied with their primary TKA.³ Reasons for ongoing dissatisfactory results seem to be not exclusively dependent on the

surgical treatment or implant associated (bone-overhang,⁴ malrotation of a component,⁵ malalignment),⁶ but also on patient age, patient expectation³ and functional improvement.⁷

In an elderly, multi-morbid but active patient population, the rapid restoration of unimpaired function, range of motion and muscle strength, are major concerns regarding possible complications, patient satisfaction and duration of recovery. Consequently, “rapid recovery” programs have been established to limit the duration of bed rest and thus leading to a quicker mobilization and discharge. Described programs focus on perioperative pain management through catheters and intraoperative injections, early physiotherapy and mobilization to ensure discharge only seven days after surgery.⁸ Independent from the surgical approach and the type of implant, most TKA includes the use of a tourniquet to provide a relatively bloodless operative field.⁹ However, the use of a pneumatic tourniquet during TKA surgery is associated with an increased risk for soft-tissue damage, postoperative complications as well as intraoperative challenges, e.g. by impaired patella mobility/tracking.¹⁰ Based on the additional possibility of thrombosis or missed arterial bleeding,¹¹ surgeons are reevaluating the necessity and benefits of tourniquet application.

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Hence it is necessary to assess, identify and optimize the crucial surgical procedure of TKA under tourniquet use. Exogenous (surgical approach, impairment of knee extensor mechanism,

implant and implantation accuracy) as well as endogenous (hypoxic tissue damage, ischemia/reperfusion injury, IR-Injury) factors are responsible for early postoperative results and

Table 1
Selected studies reporting outcome parameters of tourniquet related muscle damage after knee arthroplasty. TQ = Tourniquet. VAS = visual analog scale for pain assessment w/o = without.

Outcome parameter	Study		year	Group size	tourniquet application	Findings	pro TQ	+/-	contra TQ
duration of surgery	Zhang et al. [25]	Meta-analysis	2014	9 trials, 442 patients (224 vs. 218)	tourniquet/no tourniquet	4.57 min less operating time with tourniquet use	x		
	Tai et al. [24]	Meta-analysis	2011	6 trials, 2 studies 432 patients (282 vs. 131)	late release (after wound closure)/early release (after cementation)	faster operating time with late release: deflation after wound closure	x		
	Yi et al. [26]	Meta-analysis	2014	8 studies, 572 patients, (239 vs. 233)	tourniquet/no tourniquet	5.01 min less operating time with tourniquet use	x		
postoperative pain	Abdel-Salam et al. [30]	original data	1995	80 patients (40 vs. 40)	tourniquet/no tourniquet	VAS less 4 h postop and less analgesic injections (5/6 vs. 3/4)			x
	Vandenbusche et al. [35]	original data	2002	80 patients (40 vs. 40)	tourniquet/no tourniquet	VAS sign. lower 6 h postop			x
	Huang et al. [31]	original data	2014	90 patients (30 vs. 30 vs. 30)	tourniquet for whole surgery/ after hardening of cement/only during cementation	no difference between three groups		x	
	Ledin et al. [33]	original data	2012	50 patients (25 vs. 25)	tourniquet/no tourniquet	VAS less in four days post surgery (VAS 4.9 vs. 4.1)			x
	Kumar et al. [39]	original data	2015	30 patients bilateral (30 vs. 30)	tourniquet/no tourniquet	VAS sign. less on day one, two, three postop			x
	Ejaz et al. [40]	original data	2014	64 patients (33 vs. 31)	tourniquet/no tourniquet	no difference on day of operation and 8 weeks postop lower VAS at day of discharge w/o tourniquet use		x	x
	Chen et al. [41]	original data	2014	64 patients (32 vs. 32)	tourniquet for whole surgery/ tourniquet from osteotomy to wound closure	no sign. difference at postop day seven		x	
	Unver et al. [33]	original data	2013	38 patients (17 vs. 21)	tourniquet with minimal pressure/tourniquet with 300 mmHg	better w/o tourniquet at day one and three postop patients with low pressure TQ with less pain postop day eight no difference between two groups postop day one and two			x
	Pfizer et al. [27]	original data	2016	90 patients (45 vs. 45)	tourniquet/no tourniquet	sign. less pain postop day four at rest and mobilisation			x
	Tai et al. [43]	original data	2012	72 patients (36 vs. 36)	tourniquet/no tourniquet	sign. less pain on postop day four			x
CK (Creatinkinase)	Huang et al. [31]	original data	2014	90 patients (30 vs. 30 vs. 30)	tourniquet for whole surgery/ after hardening of cement/only during cementation	less CK in group w/o tourniquet			x
	Tai et al. [43]	original data	2012	72 patients (36 vs. 36)	tourniquet/no tourniquet	sign. Less CK on postop day one and two			x
CRP (C-reactive proteine)	Huang et al. [31]	original data	2014	90 patients (30 vs. 30 vs. 30)	tourniquet for whole surgery/ after hardening of cement/only during cementation	sign. less CRP in group with tourniquet during cementation only on postop day two and three			x
	Tai et al. [43]	original data	2012	72 patients (36 vs. 36)	tourniquet/no tourniquet	sign. Less CRP on postop day two and four			x
IL-6 (Interleukin 6)	Huang et al. [31]	original data	2014	90 patients (30 vs. 30 vs. 30)	tourniquet for whole surgery/ after hardening of cement/only during cementation	least IL-6 activity (23.0 +/- 23.4 pg/ml) in group with tourniquet during cementation only on postop day three			x
duration of hospitalization	Vandenbusche et al. [35]	original data	2002	80 patients (40 vs. 40)	tourniquet/no tourniquet	no difference (11.2 days vs. 11.8 days)		x	
	Abdel-Salam et al. [30]	original data	1995	80 patients (40 vs. 40)	tourniquet/no tourniquet	shorter w/o tourniquet (12 days (9 to 20) vs. 12 days (8 to 19))			x
	Huang 2015 [36]	Meta-analysis	2015	2 studies, 160 patients (80 vs. 80)	late release (after wound closure)/early release (before wound closure)	no difference found regarding hospitalization		x	
strength	Dennis et al. [44]	original data	2016	28 patients bilateral (28 vs. 10/18)	tourniquet after cementation/ no tourniquet or during cementation only	patients better after 3 weeks and 3 months			x
	Abdel-Salam et al. [30]	original data	1995	80 patients (40 vs. 40)	tourniquet/no tourniquet	faster in straight leg raise w/o tourniquet (4.6 days vs. 2.4 days)			x
	Unver et al. [33]	original data	2013	38 patients (17 vs. 21)	tourniquet with minimal pressure/tourniquet with 300 mmHg	no difference in day of straight leg raise		x	

complications and finally the beginning of a successful rehabilitation. These endogenous factors and their contribution to the concerns mentioned earlier in the convalescent period following TKA have not yet been analyzed on a molecular basis and will be the key topic of this review.

1.1. Exogenous – iatrogenic factors – type of implant

The primary goal of TKA is the restoration and improvement of joint function in arthritis. Therefore, the focus lies on resurfacing the damaged joint and on the annihilation of existing ligament insufficiencies to restore a stable and simultaneously functional joint, especially in revision-surgery. Osteoarthritis of the knee joint is observed in varying manifestations, consequently different surgical techniques and implants may be used during surgery, e.g. for unicompartmental arthritis concerning the medial or less common the lateral compartments, a unicompartmental implant (UKA) might be used. Epidemiologically, most cases are diagnosed with tri-compartmental arthritis and are therefore treated with a so-called total knee arthroplasty (TKA). Regarding modern developments in surgery, e.g. computer-navigation, patient specific instrumentation,¹² or patient individual arthroplasty,¹³ increased scientific effort has been made to prove the superiority of a specific surgical technique or implant design. Based on the plurality of documented highly standardized conventional TKA, documented outcomes¹⁴ can be seen as a reliable “gold-standard” for any new implant, implantation system or operating procedure. Whereas vast amounts of research have been published on different types and variable designs of implants the comparison of these outcomes are explicitly not mattered by this review.

1.2. Exogenous iatrogenic factors: surgical approach

In times of minimally-invasive surgery, surgical approaches minimize associated soft-tissue damage and its possible adverse effects such as blood loss, intramuscular hematoma and wound infection. A survey by Berry and Bozic⁹ revealed that the medial parapatellar approach is most commonly used by surveyed surgeons (71%), whereas the midvastus (23%), subvastus (7%) and a lateral approach are further established options. Still, the chosen approach depends on the surgeon's experience and preferences and on the during surgery necessary tissue exposure.

The medial parapatellar approach, introduced in 1879 by Langenbeck,¹⁵ splits the patellar tendon, the medial patellar retinaculum and the quadriceps tendon up to the beginning of the muscle tissue of the vastus medialis muscle. This is somewhat inversely equivocal for the lateral parapatellar approach. Therefore, no muscle tissue is harmed surgically, but the extensor mechanism is longitudinally split and consequently the patellar blood flow might be damaged.¹⁶ Hofmann et al.¹⁷ introduced the sub-vastus approach to resolve this problem and avoid possible complications. Still, no muscle tissue is harmed, as the incision is made from the inferior edge of the oblique vastus medialis muscle, while the fascia is supposed to stay intact.¹⁸ Results in terms of range of motion and straight leg raise¹⁹ have been shown to be superior 4–6 weeks postoperatively, but align in long-term.²⁰ Interestingly, the mid-vastus approach, which splits the quadriceps tendon to the apex of the suprapatellar pouch and dissects through the full thickness of the muscle fibers parallel to its longitudinal axis,²¹ has also shown comparable clinical results after two years follow-up.²² In summary, no superior surgical technique in long term has evolved and thus direct muscle injury may not be further limited. Indirect muscle damage via tourniquet application occurs on a regular basis.

1.3. Endogenous iatrogenic factors: tourniquet application

Numerous meta-analyses and reviews have documented important clinical outcome parameters of TKA and their association to the application of a pneumatic tourniquet. Mainly, the duration of surgery, blood loss and possible adverse effects (deep vein thrombosis, DVT; pulmonary embolism, PE) were analysed.^{23–26} Especially in arthroplasty, the prevention of bleeding from the reshaped bone stock by tourniquet application and therefore, the improved cementation process is believed to be a crucial benefit regarding long term results.²⁷ While the use of a tourniquet is favorable regarding intraoperative blood loss and duration of surgery,^{23,26} meta-analyses are ambiguous regarding overall blood loss and transfusion rate. Authors emphasize the heterogeneity of the included studies, concerning whether blood loss was calculated or measured and the time of measurement.^{24,28} Surgery without a tourniquet is proven to be beneficial for avoiding DVT, PE,²⁵ infection and other minor complications.²³ Interestingly, studies recording hypoxia and wound oxygenation were mostly not included in meta-analyses, being claimed insignificant as so-called “irrelevant outcome measures”.²³

To evaluate tourniquet associated muscle damage, data investigating tourniquet use, duration and pressure were conducted. These studies were filtered for outcomes altered through significant muscle damage, including the duration of hospitalization, subjective pain, blood parameters and strength measurements. Functional scores like range of motion (ROM) were consciously excluded because measuring methods were heterogeneous^{29,30} and might also be implant-dependent. In the following paragraphs, muscle damage associated outcomes in the context of tourniquet application have been summarized (see Table 1).

1.3.1. Duration of hospitalization

A scientific comparison of tourniquet vs. non-tourniquet surgery found no significant differences in duration of hospitalization, mean times ranging from 3 to 12 days.^{30–36} These data indicate no potential benefit regarding cost-effective earlier discharge. Considering mean costs of 323€ per inpatient day in university hospitals, up to 1125€/d in intensive care units in the Netherlands³⁷ and the linear increase of total costs across 50 states in the US from 1102\$ in 1999 to 2212\$ in 2014,³⁸ the great economic potential of rapid recovery programs becomes obvious.

1.3.2. Postoperative pain

Pain resulting from tourniquet application during TKA seems to be very challenging for the treating surgeons as it contributes greatly to the discomfort of patients, ranging from four to seven on the visual analogue scale (VAS) within the first three days after surgery.^{39,40} Caused by the side effects of tourniquet use, such as physical damage and reperfusion injury, the postoperative pain might represent damage and even fibrotic-events in muscle tissue.³³ Most of the studies comparing tourniquet vs. non-tourniquet showed significantly lower mean VAS scores in the early postoperative phase (four to six hours post-surgery) in the non-tourniquet group.^{30,35} Furthermore, patients of the non-tourniquet surgery group indicated lower subjective pain intensity on each of the four days post-surgery^{33,39} at rest and mobilization,²⁷ as well as at the day of discharge.⁴⁰ Reduction of tourniquet time or reduced applied tourniquet pressure has shown to reduce postoperative pain in the postoperative phase up to three days post-surgery as well.⁴¹ Unver et al.³² investigated 17 patients with controlled hypotension and minimal tourniquet inflation pressure (169.7 ± 7.9 mmHg) and 21 patients with normotensive anesthesia and conventional inflation pressure (304.7 ± 15.0 mmHg). After 24 and 48 h no significant difference was seen in mean pain scores, but at discharge after eight days the mean pain score of patients

with minimal inflation pressure was significantly lower. Surprisingly, Huang et al.³¹ and Mittal et al.³⁴ found no significant differences in VAS when the tourniquet was used for a shorter duration. One week after surgery the priorly noted differences in pain sensation were compensated in most studies, a period of regeneration comparable to pain after performing drop jumps until exhaustion, where muscle soreness peaks 12–48 h post-exercise and disappeared almost completely after five days.⁴²

1.3.3. Blood parameters

Huang et al.³¹ had patients choose between three different intraoperative tourniquet protocols (no-tourniquet, cementation only tourniquet, complete surgery tourniquet) and collected blood samples postoperatively. Muscle damage markers peaked in all patient groups on postoperative day two. Despite similar baseline measurements, serum creatinekinase (CK) levels, hematocrit and hemoglobin levels in patients with tourniquet use during cementation only, were significantly lower on all three postoperative days. C-reactive protein (CRP) and interleukin-6 (IL-6) levels of subjects with tourniquet application during the entire surgery were higher on all three days post-surgery compared to those of the other groups. Tai et al.⁴³ compared blood samples after TKA of a non-tourniquet and a tourniquet group. In this study the tourniquet was inflated to a pressure equaling the patient's systolic blood pressure plus 100 mmHg (instead of a fixed 300 mmHg pressure) and was released after the joint capsule had been closed. The results showed significantly higher activity of CK and levels of CRP in the non-tourniquet group, while no significant difference between the groups regarding myoglobin levels was found. However, the duration of surgery was shorter in the tourniquet group than in the non-tourniquet group with a mean of 72.0 (± 8.4) minutes compared with 78.3 (± 14.9) minutes respectively ($p = 0.02$), which may account for the higher levels of inflammation and muscle damage markers in the non-tourniquet group. Remarkably, in given data of both authors,^{31,43} mean CK levels only ranged from below 50 to 214 U/L, which these authors claim is still in the range of reference values of healthy subjects. Therefore, it might be questionable if CK is an optimal marker regarding muscle damage in the evaluation of tourniquet use in TKA.

1.3.4. Strength measurements

Dennis et al.⁴⁴ investigated isometric lower extremity strength in 28 patients with bilateral TKA, operated unilaterally with- and unilaterally without a tourniquet. The non-tourniquet leg showed significant greater quadriceps strength three weeks (approx. 14% greater) post-surgery, which persisted up to three months (approx. 7% greater) post-surgery. These authors conclude that the greater reduction in quadriceps strength in the tourniquet leg appears to be associated with muscle damage from tourniquet-induced ischemia or even direct compressive injury. Also, Dreyer recently proposed muscle loss of up to 1% daily for 2 weeks postoperatively and characterized protein activity during TKA earlier.⁴⁵

1.4. Endogenous iatrogenic: tourniquet's adverse effects

The application of tourniquets to obtain benefits in surgical care simultaneously causes a tremendous physiological challenge for skeletal muscle tissue in patients: the ischemic condition as well as the following reperfusion of the tissue have to be considered. Most importantly, several case reports documented the development of rhabdomyolysis in TKA- or other orthopedic surgical procedures, basically attributed to the use of a pneumatic tourniquet.^{46,47} Regarding different applied tourniquet-pressures (300–350 mmHg) as well as different periods of application time (50–>300 min) in the formation of rhabdomyolysis, a clear statement

about the limits of tourniquet application is almost impossible.⁴⁷ Cellular and ionic alterations in the ischemic stressed muscle may induce immense soft-tissue damage, characterized by fiber disruptions, apoptosis,⁴⁸ necrosis,⁴⁹ inflammation and interstitial edema.⁵⁰ Furthermore, the onset of extensive muscle damage can lead to systemic lethal pathologies associated with inflammatory syndromes, acidosis, hyperkalemia or rhabdomyolysis-induced renal impairment associated with myoglobinuria.⁵¹ In this context, Turkmen et al.⁵² recently were the first to report an extensive rhabdomyolysis after proximal tibial osteotomy by using a pneumatic thigh tourniquet, illustrating the importance to improve surgical tourniquet application. Therefore, to classify the potential pathological impact on skeletal muscle physiology, it is important to illustrate the underlying mechanisms of tourniquet application.

1.5. Endogenous iatrogenic: molecular mechanisms in tourniquet-stressed skeletal muscle tissue

The time under ischemia as well as the following reperfusion of the ligated limb has to be considered crucial phases for skeletal muscle tissue as well as its effect on the following rehabilitation. Observed alterations in cellular homeostasis, an increased formation of reactive oxygen species (ROS) and the onset of an acute inflammatory response are accountable for the illustrated tissue stress, which is also responsible for the onset of rhabdomyolysis in the affected limb. The mechanisms underlying these dramatic changes in tissue morphology can be differentiated in initial events during ischemia and alterations due to the reperfusion stress after tourniquet release (I/R-injury). Consequently, to demonstrate changes ranging from cellular alterations to extensive damage in ischemically stressed skeletal muscle tissue, the pathophysiological impact of acute and prolonged ischemia and the reperfusion of blood into the stressed tissue will be discussed below.

Phase 1: Ischemia In the context of orthopedic surgery, tourniquets are usually applied with a pressure of 220–450 mmHg for up to >240 min.⁵³ In the beginning, the acute ischemic condition causes a shift in energy supply from aerobic to anaerobic metabolism to sustain the ATP-level by transforming accessible glucose and glycogen to lactate.⁵⁴ This initial change in energy metabolism requires the concomitant development of a cellular acidosis by increased formation of protons (H^+).⁵⁵ Due to the limited glycogen pool, prolonged ischemic conditions presuppose a subsequent substrate exhaustion,⁵⁶ which leads to a failure of ATP-depending systems such as Na^+/K^+ -ATPases.⁵⁷ In collaboration with the incidental intracellular acidosis, an enhanced activity of Na^+/Ca^{2+} -Exchanger is observed,⁵⁸ which is inter alia responsible for an uncontrolled influx of Ca^{2+} -ions through membrane depolarization.⁵⁷ Furthermore, it is presumable that a prolonged ischemic period will decrease the Ca^{2+} -reuptake by SERCA, as previously observed in cardiomyocytes.⁵⁹ This implies a consecutive accumulation of Ca^{2+} -ions in the sarcoplasm. Furthermore, the depletion of the intracellular ATP-level result in an increased production of ROS⁶⁰ by enhanced activity of xanthine-oxidase⁶¹ and changes in mitochondrial function.⁶² The degree of skeletal muscle damage by ischemia increases with prolonged time under O_2 -abstinence.⁶³ Evidence for the onset of muscle edema is documented immediately after ischemic application and represents the early stage of damage to the muscle tissue. Prolonged ischemic conditions are responsible for partial myonecrosis, detectable after four hours of ischemia which further enhances to substantial irreversible histopathological necrosis after up to seven hours of ischemia.⁵¹ This is potentially due to the impact of Ca^{2+} -dependent proteases and ROS-related oxidative reactions of cellular- and sarcolemmal components.

Phase 2: Reperfusion However, similarly it has become apparent that the subsequent reperfusion, the restoration of blood flow after an ischemic period, is a crucial event in skeletal muscle physiology as well, through increasing the amount of stress leading to further cellular damage in the soft tissue.⁶⁴ In consideration of its far-reaching impact, I/R-injury is not simply equitable to a local development of tissue damage such as fiber disruption or intestinal edema. It is rather a serious medical condition which may vary from compartment syndrome in the previously ligated extremity⁶⁵ to systemic inflammatory syndrome, in extreme renal impairment or -failure due to rhabdomyolysis.⁶⁶ Therefore, a lot of research was done to understand the mechanisms of I/R-injury. Several causal components in the development of I/R-injury were identified, including particularly the initiation of pro-inflammatory responses.⁶⁷ Previous observations revealed that during ischemic conditions the increased existence of ROS provoked an enhanced activation of nuclear-factor-kappa B (NF-κB) in muscle cells,⁶⁸ subsequently leading to the expression of neo-antigens⁶⁹ and pro-inflammatory cytokines, like IL-6, IL-1 or TNF-α. These neo-antigens, such as P-selectin or I-CAM1⁷⁰ are successively transferred to the cell surface⁷¹ and show an extensive affinity for interactions with immunoglobulin M (IgM) during ischemia already. The following initiation of the classical complement pathway by the formation of C3b complex causes the formation of the so-called membrane attacking complex,⁶⁷ and is furthermore leading to the manifestation of key inflammatory related actions, such as changing the vascular permeability, increased extravasation and abnormal cell signaling.⁷² Besides the presentation of chemokines at the cell surface, the co-generated complement components, such as C3a and C5a, act as chemotactic agents, which in synergism with the ischemic-induced leukocytosis⁷³ support an increased activation and diapedesis of neutrophils⁷⁴ into the stressed muscle tissue. Consequently, the increased myeloperoxidase activity of infiltrated neutrophils presupposes additional ROS-related damage in skeletal muscle tissue.⁷⁵ In summary, current evidence suggests that the complement- and immune systems can be highlighted as critical players in formation of I/R-Injury in skeletal muscle. Further confirmation about the crucial influence of the classic complement pathway was obtained through studies with C3-deficient animals, which revealed less skeletal muscle damage in a hind limb model of I/R-Injury.⁷⁶

In addition to the initiation of pro-inflammatory immune reactions, the muscle cell homeostasis is disturbed by an increased accumulation of intracellular Ca^{2+} ,⁷⁷ due to the during reperfusion still in “reverse mode” acting NCX⁷⁸. The magnitude of Ca^{2+} -induced reperfusion damage seems to be dependent on the fiber composition of the stressed muscle. Studies revealed that less slow-twitch muscle fibers get damaged through I/R-injury, compared to fast-twitch ones.⁷⁹ Based on these discoveries hypothesis drew conclusions about the higher mitochondrial content of slow twitch fibers, which potentially act as a buffer against lethal Ca^{2+} -overload. Furthermore, the increased metabolic rate of fast-twitch fibers presupposes faster substrate exhaustion during ischemia which implies less capacity to act against cellular alterations during prolonged ischemia or even reperfusion.⁷⁹

2. Conclusion and future perspective

The application of a tourniquet to restrict intraoperative bleeding during TKA is beneficial for surgery regarding technical aspects while it is simultaneously challenging the patient's skeletal muscle. Reported clinical outcomes suggest that the use of a pneumatic tourniquet is not always associated with an elevation in known muscle damage markers, but measurements of muscle performance demonstrate that the skeletal muscle tissue especially of the extensor mechanism is profoundly affected – at least

temporarily. Due to the current discussion in TKA-care about “rapid-recovery”, broaching the issue of skeletal muscle impairment and damage during surgery is essential. Equally, the large amount of case reports which refer to the onset of rhabdomyolysis caused by tourniquet application and the lack of a scientific consensus about evidence-based tourniquet-use presuppose the examination of skeletal muscle protection during surgery. Whereas tremendous effort has been made by the surgical side to improve protection through different surgical techniques (e.g. minimal-invasive surgery), only little attention has been paid to the role of preparing the muscle in advance of a stressful event, such as TKA. The concept of preparing the body via physical exercises before surgery is called “prehabilitation”.⁸⁰ It is proven, that preoperative strength, the range of motion, flexibility, subjective pain and the ability to complete functional tasks are crucial predictors for recovery and postoperative outcomes after TKA.⁸⁰ This data suggests, that a trained skeletal muscle is presumably more able to resist against the mentioned cellular and metabolic changes during tourniquet use. Therefore, to achieve skeletal muscle protection, the application and investigation of different surgical techniques was and still is a sufficient approach to enhance future medical care. However, it is important to keep in mind that the skeletal muscle is a highly adaptable tissue, in which performance or even metabolic resistance can be extensively modified through regular training. Therefore, future studies should focus on investigating possible pre-surgical intervention strategies to increase patient's internal resistance, which may be modified by long-term prehabilitation or even short-term preconditioning.

Conflict of interests

All Authors declare that there is no conflict of interest.

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