



RĪGAS  
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**LAURA LOGINA**

**AMPUTATED PARTS OF UPPER EXTRIMITY  
BONE TISSUE PROPERTIES CHANGES  
AFTER A LONG TIME ISCHEMIA**

Summary

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Scientific supervisor:

**Dr.med., assoc. professor Dainis Krieviņš**

**Approved reviewers:**

- **Dr.habil.med., professor Jānis Vētra (RSU)**
- **Dr.habil.sc.ing., academician Ivars Knēts (RTU)**
- **Dr.habil.med., professors Haralds Jansons (State Emeritus Scientist)**

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Secretary of Promotion Council.  
Dr habil. med., professor  
Liga Aberberga - Augskalne

*L. Aberberga*

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## 1. Abbreviations

UV	-	ultrasound velocity
USM	-	ultrasonometry
Ca	-	calcium
HA	-	hydroxiapatite
VFK	-	bone of the middle phalanges
MKK	-	metacarpal bone
PFK	-	bone of the proximal phalanges

## 2. Importance of the problem

Upper extremities traumas are common among people with the different social living standards. One of the most severe traumas of the extremity is amputation of the hand or fingers. Most of all traumas happen at work and among the young people. It is very important to restore function of the damaged extremity. The only possibility to reconstruct the function of the damaged extremity is replantation. However, it is necessary to evaluate the condition of the soft tissue, blood vessels and nerves, and bone in the amputated part and the stump before the start of replantation. Amputated part and bone as one of the structure is suffer from long time of ischemia - three, five and sometimes sixteen hour. Possibility to made successful restore of blood circulation in the amputated part is depend of ischemia time, level of the amputation, damaged structure as well as age, comorbities and addictions of the patient as well as others factors.

The early postoperative complications after replantation are arterial and venous thrombosis with following thrombosis as well as infection. Inadequate venous drainage with following thrombosis is a most common problem. Often these complications are associated with soft tissue condition but more than half of all tissue in the fingers is bone. Bone is important part of the finger and changes in the bone because of long time ischemia can be important in the development of the most often complication - venous congestion development. Some experimental and clinical studies showed that bone can deposit blood and venous outflow improvement through the bone could be one of the possible ways how to solve venous congestion development in the replanted part.

Investigation of the bone in the amputated part in the case of long time of ischemia is complicated. There are lot of investigation methods but most of them are invasive, difficult to prepare or expensive and they are not appropriate to use in the clinical situation of the amputation of the upper limb fingers.

Ultrasonometry (USM) is investigation method were velocity of ultrasound propagation is detected. This method is achieving more and more popularity nowadays. Bone ultrasound velocity characterizes biomechanical properties like density and structural organization.

There is not any study about importance of the bone changes after the long time ischemia as well as exact role in the development and compensation process of venous congestion in the case of upper extremity finger replantation. Possibility to detect changes in the bone due to the long ischemia time potentiality could give chance to predict venous congestion development as well as realize prophylactic actions.

### **3. Objective of the work**

Investigation of the bone property changes due to long time ischemia in the case of upper extremity amputation.

### **4. Terms of reference**

1. Development of the USM methodology for investigation of the amputated part bone condition.
2. UV changes detection in the extremity bone tissue after long time ischemia in experimental model.
3. UV changes detection in the extremity bone tissue after long time ischemia in practice.
4. Development of recommendation for use to the patients after the upper extremity replantation to minimize venous congestion development as well as obtaining of the better function result.

### **5. Hypothesis of the work**

1. It is possible to use USM for detecting changes in the bone due to long time ischemia.
2. Changes in the bone after the long time ischemia can promote venous congestion development.

### **6. Scientific novelty and practical value of the study**

1. Detected acoustic properties changes in the bone of the upper extremities fingers after the long time ischemia.
2. Evaluated importance of the bone condition in the development of the venous congestion as a replantation complication.
3. Recommendations to minimize venous congestion development after the upper extremity replantation presented.

## 7. Materials and methods

### Experimental work

Experimental part was done in the Clinical institute of the Veterinary medicine faculty of the Latvian University.

Czech Albino (Czech Albino) rabbits were used. All animals were carried due to standard conditions with 12-hour darkness cycle. All animals were adult ( $12 \pm 1$  months), weight  $3,94 \pm 0,24$  kg.

At first basis UV measurements were done on seven animals (14 objects) – 56 measurements (four times in every localization). UV measurements were done in the upper extremity bones – distal  $1/3$  of the radius.

We used six objects for experimental measurements - after the total, acute blood circulation disruption (measurements were done in the right paw in three cases and in the left paw in three cases as well as four animals were female but two - male). First experimental measurements were done just after animals were sacrificed and then repeated periodically in dynamic after the 3, 10, 17, 33, 52, 80 hours after total, acute blood circulation disruption. Experimental model were developed close to the clinical situation when amputation of the upper arm extremity were happened. Measurements were done distal from fracture level – in the place without direct damage from mechanism of the amputation. Measurements were done in the site with most thin skin-subcutaneous tissue were reached as well as special gel (Aquasonics 100, Parker Labs) were used. 168 measurements were done at all (we repeated four times in the every location).

Animals were not used only for this investigation. Measurements were made after the sacrificed due to other study needs.

### Clinical work

Study were done in the RAKUS clinic “Gaiļezers” with cooperation of The Center of Plastic and Reconstructive Microsurgery of Latvia. Measurements were done on 17 patients with total amputation of the one or more than one upper extremity fingers. Patients come to the clinic on purpose to treatment. Age 19-68 year (mean  $41,9 \pm 11,75$  year), 14 were male (82,4%) and 3 female (17,6%) and 9 patients had trauma to the right hand but 8 – to the left hand fingers.

Patients only with total one or more than one upper extremity finger included in this study - in the amputated finger from the moment of trauma till moment of measurement were not any blood circulation. In all cases there was warm ischemia of the amputated part. Patients with any visual soft tissue or X-ray detected bone damage were excluded. All patients were older than 18 years and without any serious comorbidity as well as without any serious upper extremity soft tissue or bone damage or injury in the past. Measurements were done to the amputated part bone distal to the level of amputation but healthy extremity symmetrical bone measurements were made as control. In the amputated part measurements were done only to the bone in the part which is not directly

damaged at the time of the trauma. In that way possibility of direct trauma damage influence on measurement value were excluded.

When physical evaluation, X-ray and clinical analyzes were done and patient was taken to the operation room measurements were done.

Patients were divided depend of measurement localization in 14 groups: groups were divided and marked like: I - metacarpal bone; II- proximal phalanges; III - middle phalanges; index depend of finger I-V finger were added.

17 patients or 29 clinical cases were included in this study. Clinical case means measurements of the one patient in the one localization. 10 patients had single clinical case but other 7 patients had more than one clinical case - measurements were done on more than one localization. 116 measurements were done in the amputated part in 14 localizations (29 clinical cases and for every localization we repeated measurements four times) and the same number in the healthy side at the symmetrical site of amputated part.

### **Measurement method**

Experimental measurement were made with USM facility - „Osteo-1” used to measure the ultrasound velocity at frequency of 250kHz.

We used probe with special concentrator. Measurements were made in longitudinal direction, measurement basis 10mm. Before every measurements calibration with standard material - Plexiglas were done.

Experimental measurements were done thought the animal skin and for better contact special ultrasound gel were used (Aquasonics 100, Parker Labs). To avoid drying of soft tissue and bone animals extremity were kept at temperature +5C to +7C in the wet material soaked with NaCl 0,9% and unwrapped at measurement time only. Weight of the amputated part was detected every time before and after measurements with electrical scale with precision one gram (Talent TE12000, Sartorius).

As guided in the literature the exact place for finger bone measurement was found in the medial or lateral side where tendons not situated as well as soft tissue amount is relatively less. The measurements in patients were done with the same USM facility - „Osteo-1” in longitudinal direction with measurement base 10mm. Measurements were made in the metacarpal bone as well as in the proximal and middle phalanges at middle 1/3. Probe was situated angle - at 45 degree to the longitudinal plane of the finger. Measurements repeated for four times every place.

### **Statistical analysis**

All measurement results were systematized with Microsoft Excel. Calculation of the mean value as well as standard deviation and standard error were made. We used Kolmogorov-Smirnov test.

Statistical analysis of the data was performed by SPSS 16.0 [USA] software.

Significant differences in the measurements were analyzed using analysis of variance (ANOVA). All differences were considered significant at a probability level of 95% ( $p=0,05$  or  $p<0,05$ ).

## 8. Results

### Experimental study

We did 224 measurements – 56 were basis but 168 experimental measurements. We used Kolmogorov-Smirnov test for detecting normal division. In further calculation we used parametrical statistic methods (t-test et al).

Value of the basis measurements were  $2113\pm 83\text{m/s}$  but UV in the experimental measurements were from  $2006\text{m/s}$  to  $2523\text{m/s}$ .

We calculate mean value as well as standard deviation and standard error in every experimental measurement time interval. Measurements were done in different days and there were not possibilities to notice time intervals between measurements very precise and therefore period of  $\pm 0,5\text{h}$  were analyze as one point.

Ultrasound velocity normal value just after the total disruption of the circulation were  $2162\pm 83\text{m/s}$  what is very close to the basis measurements. Then after ultrasound velocity started increase till 17h beyond circulation disruption and paw disarticulation normal value was  $2341\pm 71\text{m/s}$ . Very fast increase of the ultrasound velocity happened in the first 3h. Then short plateau period is seen at interval 3h to 10h after the total disruption of the circulation. In the period 10h till 17h there are seen very sharp increase of the ultrasound velocity. At the highest point ultrasound velocity reach  $2341\pm 72\text{m/s}$ . Ultrasound velocity started to decrease in the period after the 17h and at the time 33h reached the same level as 3h to 10h after the total disruption of microcirculation. Until 80h after the circulation was disrupted ultrasound velocity reaches level close to the beginning -  $2195\pm 67\text{m/s}$ . All results shown in Fig.1.

We analyzed data from multiple parameters. At first we analyze result depend of extremity were measurements were done. There were not statistically significant difference between extremities in the first period of time ( $t=1,239$ ,  $p=0,219$ ) and reaching maximal value 17h after circulation disruption ( $t=1,439$ ,  $p=0,164$ ) as well at the end point ( $t=1,725$ ,  $p=0,98$ ).

We analyzed measurement results depend of animal sex and there were not significant difference between both sexes.



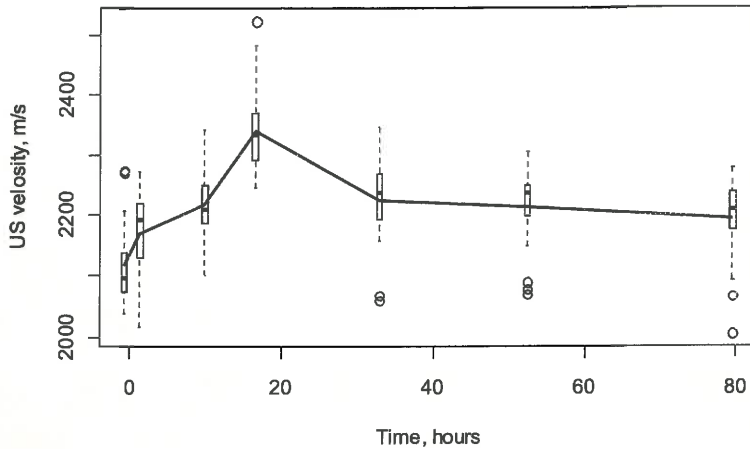


Fig.1. Mean UV in all group measurements with standard deviation.

### Clinical study

We did 116 measurements on 17 patients (29 clinical cases) in the amputated part distal from amputation level and the same amount - 116 measurements in the healthy side symmetrical places to the amputated part measurement site.

We used Kolmogorov-Smirnov test for detecting normal division. In the healthy ( $Z=1,115$ ;  $p=0,166$ ) as well in the amputated part ( $Z=1,096$ ;  $p=0,181$ ) result were at normal division. Therefore in further calculation we used parametrical statistic methods (t-test et al).

UV in the healthy side bones were 2003m/s to 2317m/s (mean velocity  $2171 \pm 68$ m/s) but in the amputated part bones UV were 2290m/s to 2550m/s (mean velocity  $2451 \pm 55$ m/s).

Leven's (*Levene's*) test showed both groups division as similar ( $F=3,255$ ;  $p=0,073$ ) and t-test verify that UV mean value are with statistically difference ( $t=34,497$ ;  $p=0,001$ ). All results shown in Fig.2.

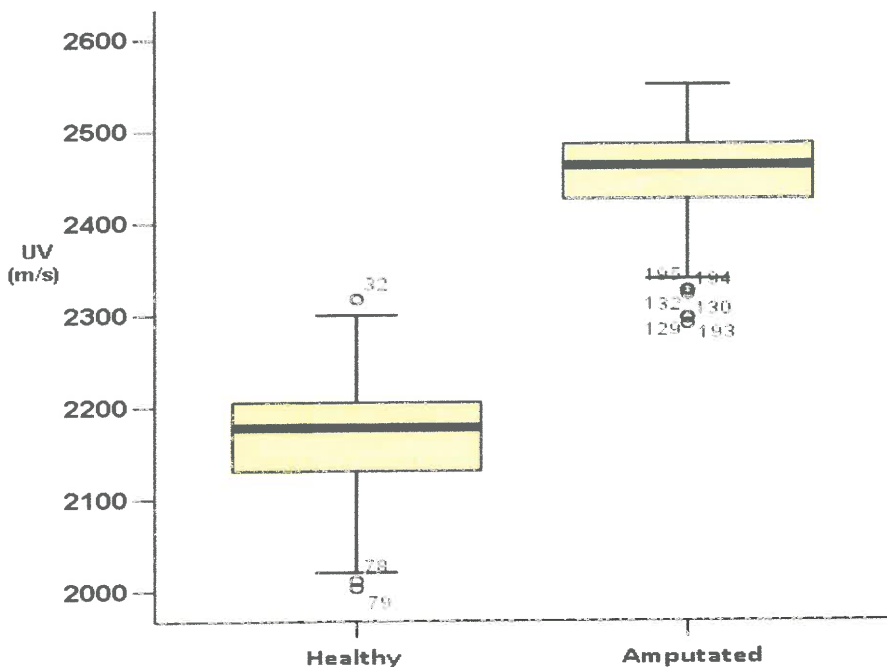


Fig.2. UV mean value in the healthy and amputated part.

Calculation of the UV difference:

**UV difference = UV in the amputated part – UV in the healthy part**

The UV difference is from 162m/s till 436m/s and the mean value is  $279 \pm 58$  m/s.

Measurements were done in all fingers – from I to V. It was important to know is there any statistical difference in UV between different fingers. Hypothesis about UV mean value similarity we tested with dispersy analysis (ANOVA) and find that mean UV in the different fingers were statistically different ( $F=5,448$ ;  $p<0,001$ ). The mean UV in the different fingers is shown in Fig.3.

We did the same analysis about UV difference between measurements at the different levels in the fingers. Dispersy analysis (ANOVA) showed that there are statistically significant difference in different levels in the fingers ( $F=11,228$ ;  $p<0,001$ ). The mean UV in the different levels in the fingers is shown in Fig.4.

Analyzing UV difference between different fingers we found that there is statistically difference between some pairs of the fingers. The higher UV is in the amputated part at level II-I, I-5 and in healthy part at level III-4 un I-5 but the higher UV difference (UV in the amputated part-UV in the healthy part) is in the level II-I, I-4 un III-V. The least UV in the amputated part is in the level I-1, I-2, I-4, III-V and in the healthy part I-4, III-5 level but least UV difference (UV in the amputated part-UV in the healthy part) is in the level I-1, I-2, III-4. All levels you can find in Fig.5.

We verify UV mean value difference in the different fingers at healthy side with Dispersy analysis (ANOVA) and found that there are statistically difference (F=19,385; p<0,001).

We compare UV at the healthy side and amputated side bones as well as depend of time of ischemia. Results you can find in Fig.6., Fig.7., Fig.8. Regression analysis showed that between UV in the healthy side bones and amputated part bones there is medium correlation (R=0,574) and coefficient of determination is R<sup>2</sup>=0,324. The 32,4% of disperse can be explain due to UV disperse in the healthy bones.

From linear regression calculations there is possible to make equation:

**UV in the amputated part bone (m/s)=1448,619+0,461 x UV in the healthy bone (m/s)**

For example if UV in the healthy bone is 2100m/s then UV in the amputated part bones must be 2448,619+0,461 X 2100=2416,719(m/s)

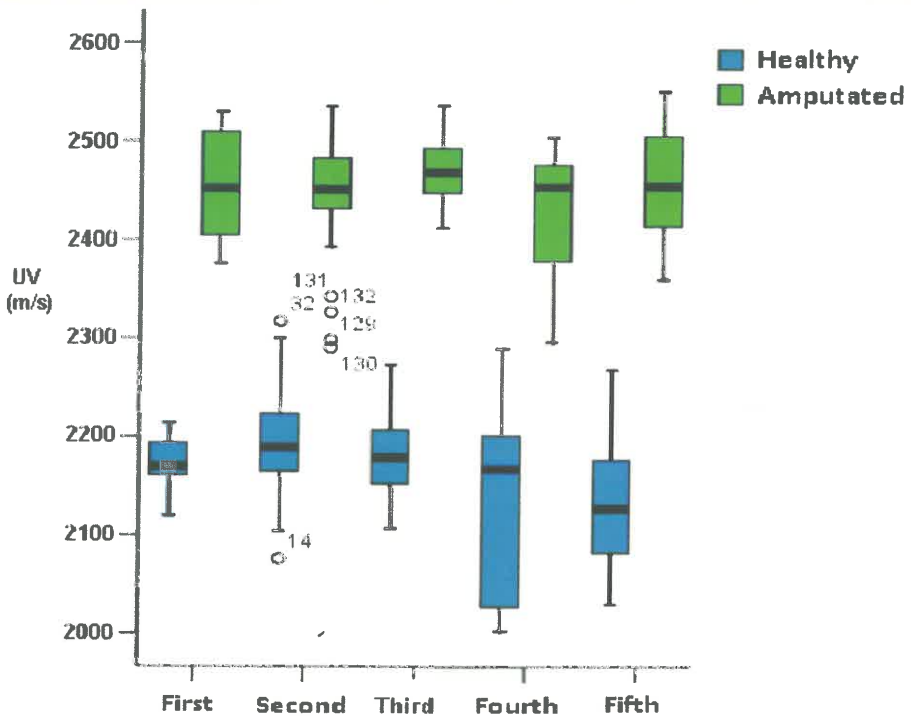


Fig.3. UV in the different fingers.

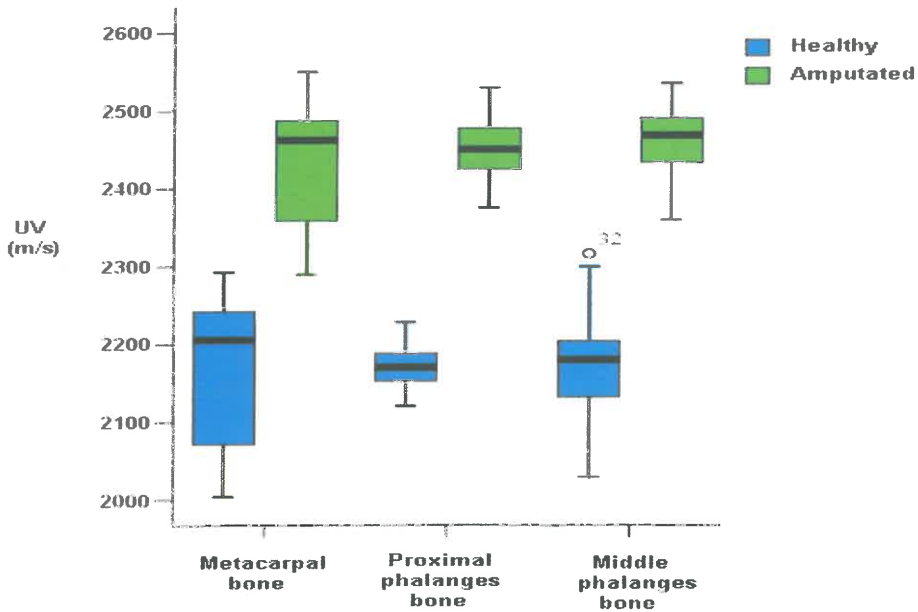


Fig.4. UV in the different levels in the fingers.

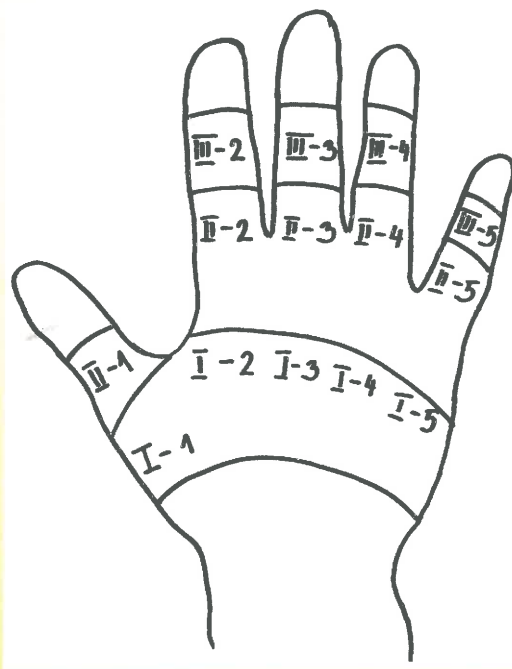


Fig.5. Levels of the measurements.

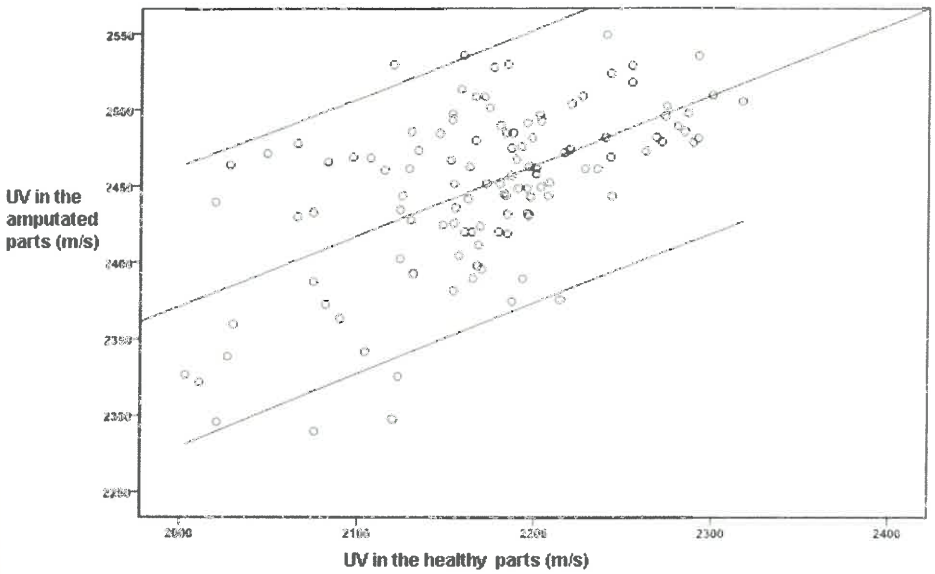


Fig.6. UV in the healthy and amputated part bones (m/s).

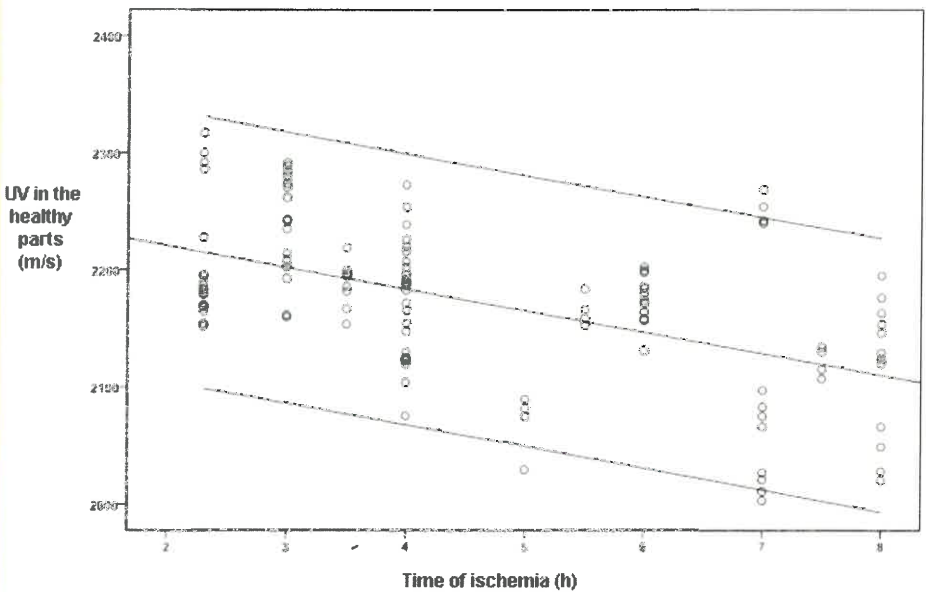


Fig.7. Correlation between UV in the healthy part and time of ischemia.

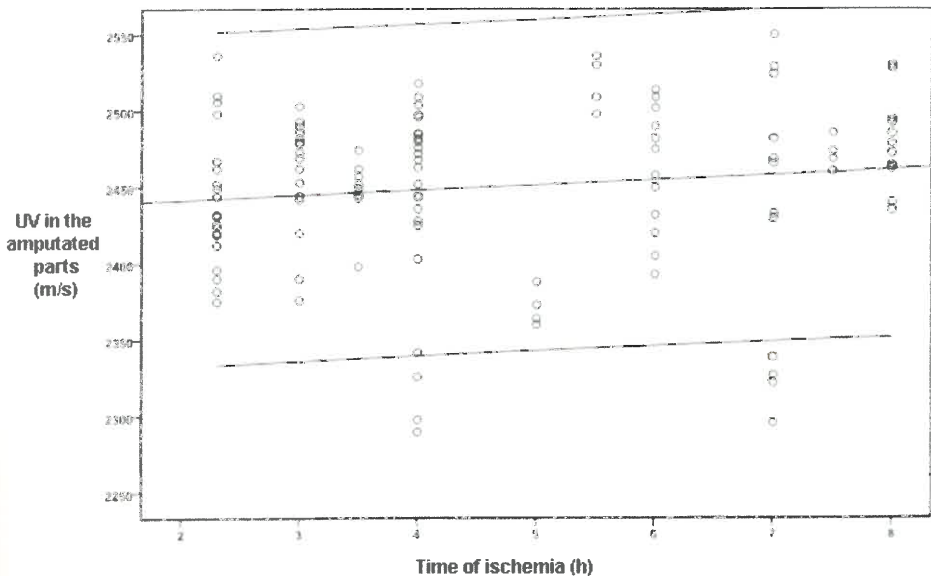


Fig.8. Correlation between UV in the amputated part and ischemia time.

Correlation between UV difference (UV in the amputated part - UV in the healthy part) depend of time of ischemia is shown in Fig.9.

Regression analysis of UV difference dependence of ischemia time showed good correlation ( $R=0,732$ ).

We couldn't compare UV between the both sex depend of ischemia time because most part of patient were male (82,4%) and in some age groups (19-39y and 60-69y) there weren't female patient. Results are showed in Fig.10.

We analyze correlation between UV in the amputated part bones and age of patient as well as UV in the healthy part bones and age and results are showed in Fig. 11. and 12.

UV difference (UV in the amputated part-UV in the healthy part) analysis depend of patient age showed that least difference is in the age group 19-30y but higher difference is in the age group 50-59y and that is showed in Fig.13.

There is not statistically significant difference between UV measurement in the male and female patients ( $t=0,525$ ;  $p=0,12$ ).

We did statistical analysis of UV changes depend of ischemia time till 5 hour and more than 5 hour. Mean UV difference in patients with ischemia time till 5 hours were 249,9m/s but if ischemia time were longer than 5 hour UV difference were 327m/s (Fig.14.)

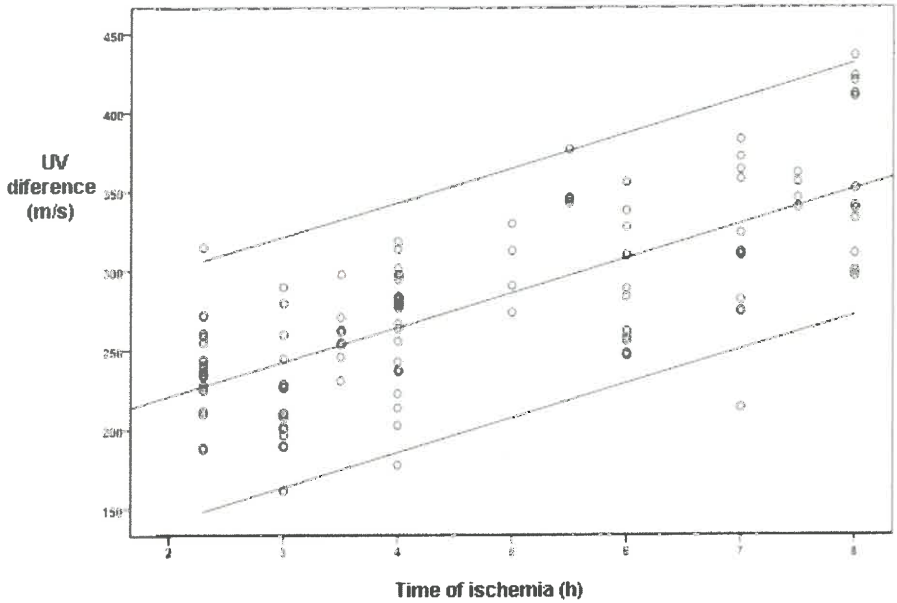


Fig.9. UV difference (UV in the amputated part-UV in the healthy part) and time of ischemia.

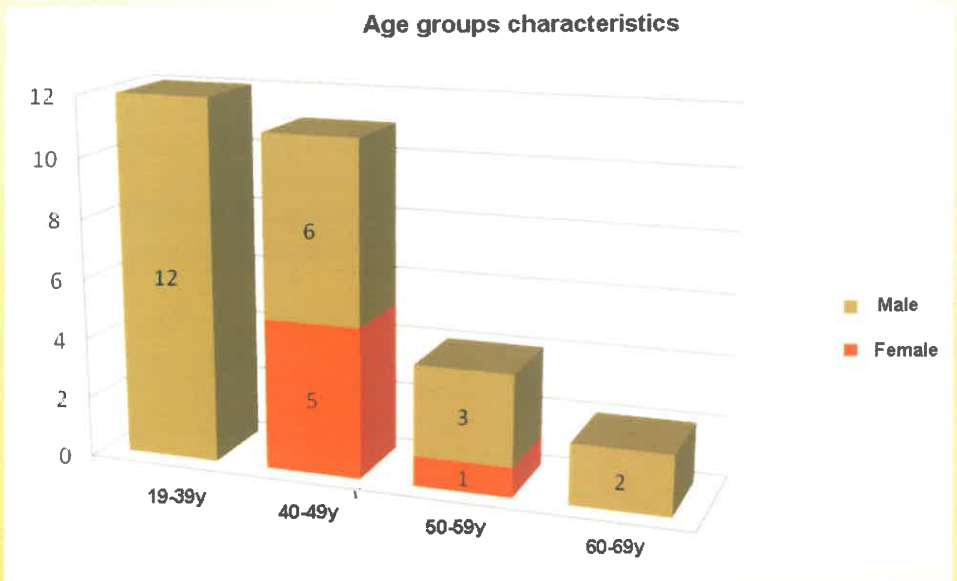


Fig. 10. Different age groups.

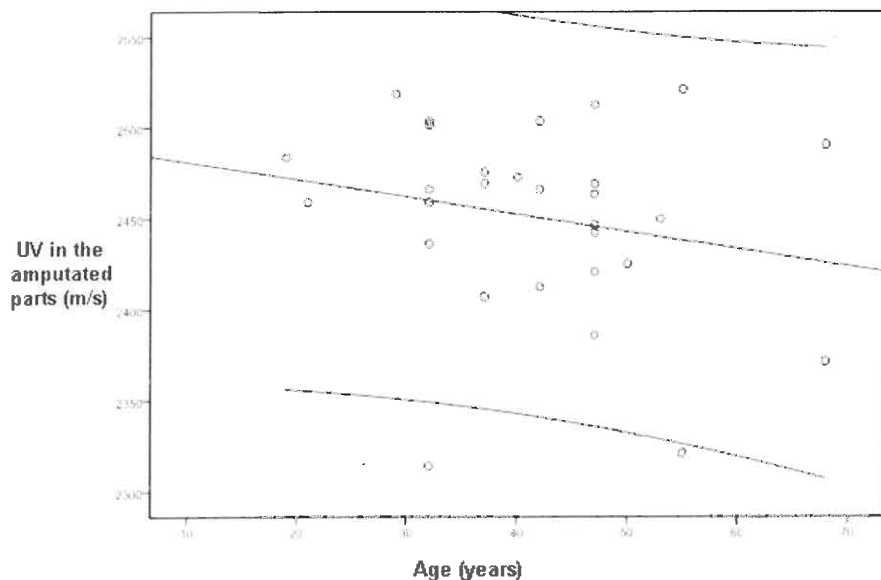


Fig. 11. Corelation between UV in the amputated part and age of the patient.

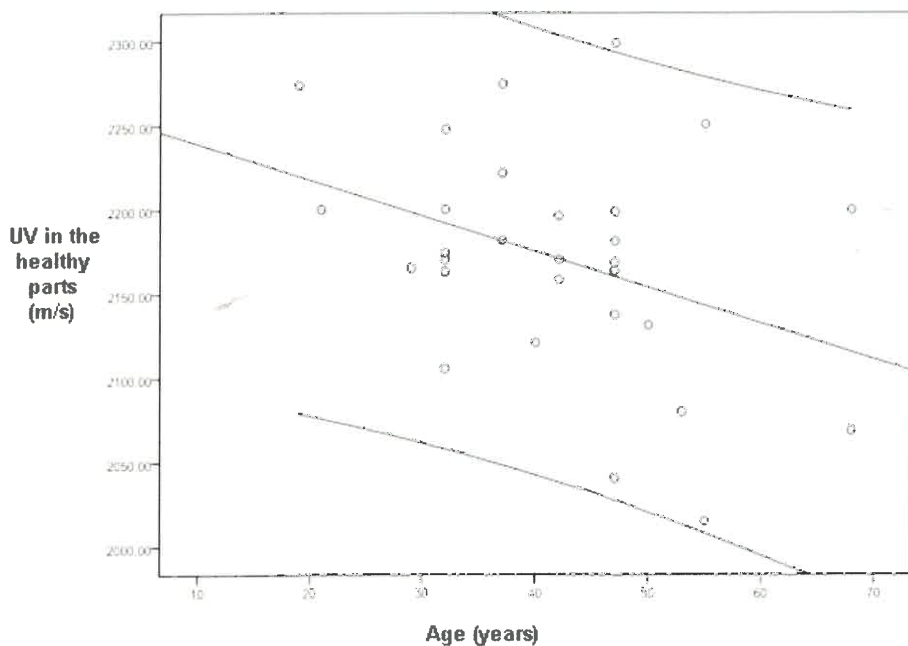


Fig.12. Corelation between UV in the healthy part and age of the patient.



### UV difference (amput.-healthy) in the groups

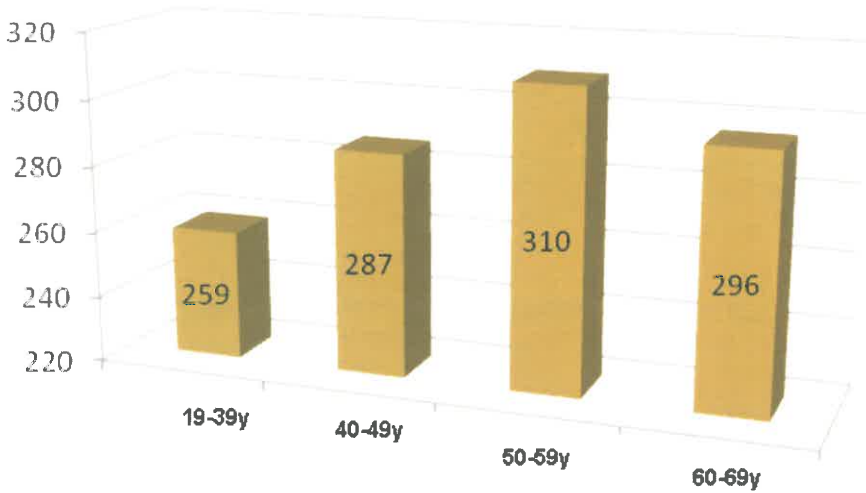


Fig.13. UV difference in the different age groups.

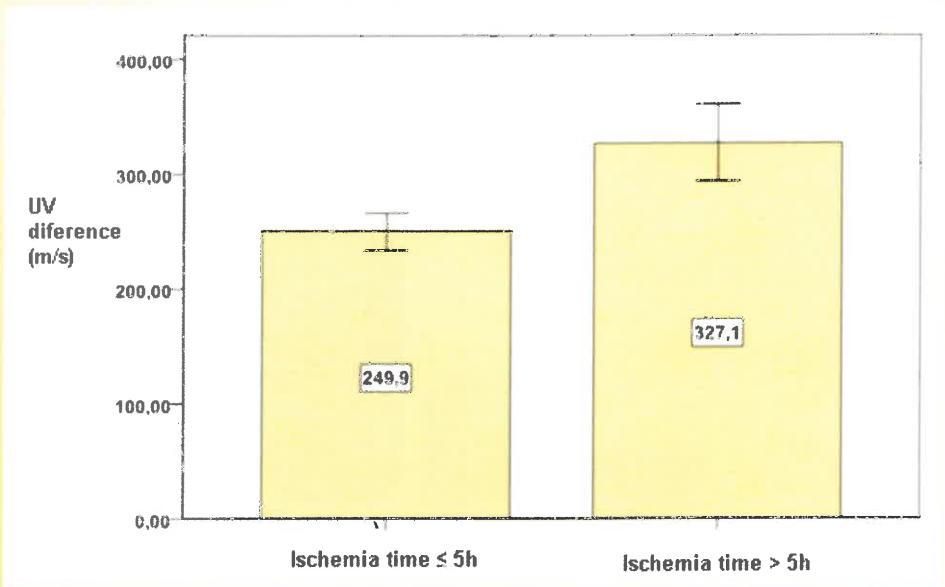


Fig.14. Mean UV difference (UV in the amputated part-UV in the healthy part) depend of ischemia time.

## 9. Discussion

Several decades have passed since the time when the first replantations took place. The results of replantations have essentially improved achieving 85-90% of survival of the replanted part. The most part of scientific publications mention successful replantation of fingers in the context of survival of soft tissues connecting this with the restoring of blood flow in soft tissues of the amputated part. However, it is accented more and more that the estimation criteria of the results should be not only the viability of the replanted part but the functional result in long term – the amount of movements of fingers, sensitivity, the condition of soft tissues as well as stability of bones. According to the data of literature, problems and complications related to the condition of bones, where the main problem is disturbance of consolidation, are observed in 40 to 50 % of cases, although this aspect is discussed comparatively seldom. Exclusively some authors pay attention to the condition of bones acknowledging that the stabilization in cases of replantation of bones is vital and creates the result of replantation. The most common problems related to tissues of bones which might arose after the replantation of bones are the prolongation of time of consolidation, lack of consolidation, mutual displace of both sides of osteosynthesis which cause angulation or rotation, vascular necrosis, stiffness of joints, osteomyelitis. It should be mentioned that there is no special system for estimation the condition of bones as well as the degree of complications related to the bone tissues in the replanted part and it is not possible to evaluate the affect of the condition of bones in the replanted part to the overall functional result of the replanted part. The angulation in the places of osteosynthesis, when the osteotomy and the correction of axis are indicated, as well as the interval of time in cases of disturbance or lack of consolidation of bones in cases of replantation of the fingers are estimated distinctively by different authors.

Replantation, by structure and function, involves very different structure – reconstruction of blood-vessels, nerves, tendons, muscles and bones. A long time ischemia certainly causes changes in all these structures. The mechanism of trauma and condition of tissues of the amputated part affects the result of replantation and the cause of complications. Venous congestion is the main complication. The importance of tissues of the amputated part in successful replantation as well as in the development of venous stasis is not wildly researched by doctors so far and therefore cannot be evaluated. Bone tissues are difficult to be studied due to their specific biomechanical features as well as complicated structure which combines organic and non-organic part. The investigation in the amputated part is even more challenging as only individual investigation methods could be used in the given clinical situation. Invasive and harmful methods couldn't be used because that kind of investigation can influence result of replantation.

The USM as a method has been created and used for denoting different changes of different bone tissues. Ultrasonic propagation along bone tissues depends on the structure of bones – on their microstructural and compositional peculiarities, as

the measurements are not invasive, the apparatus is portable, it is not pernicious, the condition of bones could be observed in dynamics and, finally, it is not expensive. However, UV has not been used for denoting the changes of bone tissues in amputated part in cases of a long time ischemia.

The tissues of extremities of rabbits are widely used as pattern for investigation the healing process after fractures and osteonecrosis as well as the development of avascular necrosis. It is acknowledged in several investigations that the contexture of bones both dogs and rabbits is similar to the contexture of the bone of men. The authors of this experimental research fulfilled the investigations using rabbits for experimental purposes.

There is difference between UV measurement done in vitro, in situ or in vivo. During our experimental investigation the member bones were not skeletised and all the measurements were performed through skin. During our experimental investigation bone tissue were not influenced mechanically or chemicalize.

The results of experimental investigation prove that as early as 3 hours after acute, total interruption of blood flow in the limb of rabbit, UV rises from  $2113 \pm 83 \text{ m/s}$  to  $2228 \pm 34 \text{ m/s}$  on average which is  $115 \text{ m/s}$  or  $5,4\%$  on average. The results of investigation allow concluding that 3 hours long ischemia causes changes of bone tissues which could be identified by USM method. With the increase of time of ischemia up to 17 hours, an intrinsic growth of UV was observed – up to  $2341 \pm 72 \text{ m/s}$ , hence the increase of UV is  $228 \text{ m/s}$  ( $10,8\%$ ) in comparison with the beginning of investigation. After reaching the maximum of UV a decline of UV was observed, although, even in 80 hours of ischemia, it did not reached the initial value but produced an increase of UV for  $82 \text{ m/s}$  which is  $3,9\%$ .

As the data of performance of similar investigations were not found, it was not possible to perform more detailed interpretation of the obtained results.

UV value are individual and can vary in one person depend of measurement localization. The reasons could be different bone structure, proportions and function. UV measurements can vary depend of apparatus, method of measurement, direction of measurement in the bone and other factors. We use one method of measurement and apparatus in both experimental and clinical work. We consider UV in the healthy extremity bone as individual rate for individual person.

The results of investigation prove that the difference between measurements between bones of both palms and between UIA in phalanges of fingers of palms for dominant and non-dominant hand of healthy individuals is not statistically credible. The difference in measurements in hands according to the gender is not statistically credible as well. Our measurement results show the same – UV in the amputated part bones is not statistically credible according to the gender, dexterity or age.

According to the data UV is widely used in diagnostics of different kind of changes of bones. The use of USM and healing in cortical tissues in UV is widely researched in Latvia. The USM method is used in several investigations for observation of abilities of lower basic extremities. The UV measurements are

fulfilled both for denoting the risk of osteoporosis and fracture. There are investigations of changes of UV in cases of different deceases, for example, celiac, diminished function of production of thyroid hormones and diabetes. UV measurements could be done with children as well. The USM method is used for denoting the UV changes for extremity bones in conditions of changed blood circulation. Performing USM measurements in the phalanges of fingers of higher extremity for patients with Reino Raynaud's phenomenon (vazospastic disturbance), a lowered extension of ultrasound speed and some structural changes of bones were observed.

Different methodologies are described in literature for performing measurements in bones of higher extremities. The most part of investigations where USM measurements have been performed in proximal phalange of fingers are done in the distal part of diphas. Substantiation for this kind of localization is the peculiarities of the bone of this area – the proximal phalange of the finger contain both cortical and trabecular bone and the phalange have a small channel of the bone. However, about 60 % of the measurements of this area show the condition of cortical bone. Most measurements are performed in proximal phalange of the III finger, although quite often the measurements are performed on the lateral surface of proximal phalange of the II till V finger. In our clinical work the measurements are performed on all the fingers. The results obtained from measurements on bones of healthful extremities indicate to the statistically reliable difference among measurements on the II and III finger anent to the measurements on IV and V finger and vice versa. Conversely, the measurements of amputated parts do not show statistically reliable difference among the results, which are performed on different fingers. The measurements performed on undisturbed blood circulation the results of UV measurements of bone tissues could vary depending on a lot of factors, which are related to the physiological condition of the concrete individual. The results of UV measurements on amputated parts which are obtained in a clinical research after interruption the blood circulation show lower distribution in comparison with the measurements on the healthy parts.

The results of the UIA measurements performed during the research on the bones of phalange of the healthy palm are equal to the results described in literature and therefore are comparable. However, the data of UIA in bone tissues which have been subject of prolonged ischemia in the case of amputation are not comparable and interpreted as similar researches have not been done so far.

The processes of drying up could affect the biomechanical features of bone tissues. Accordingly, several authors of this kind of investigations advise to humidify the samples of bones, if possible. During our experimental investigation we fulfilled several activities in order to prevent the drying up – the member bones were not skeletised and all the measurements were performed through skin. Besides, UIA measurements in experimental investigation were performed in the front paws of

rabbits and in a clinical investigation of human`s amputated finger at the level which was outside the direct zone of amputation (fracture). Patients with any visual soft tissue or X-ray detected bone damage were excluded. Nevertheless, this factor should definitely be taken into account while interpreting the results of investigations.

In clinical practice mainly the rentgenological (X-ray) investigation method is used to diagnose status of the damaged part. Early changes after the long ischemia could not be detected by using X-ray, only the consequences of changes caused by ischemia or degenerative changes can be shown. The other methods of investigation of bones have not been applied in clinical practice.

The changes of bone tissues in amputated part are quantitative and qualitative. Changes, as a result of a long time ischemia, appear both - in organic and non-organic part of the amputated part of bones. The results of several investigations prove that even one hour long ischemia causes the death of bone cells. The changes are also observed in extracellular matrix which main organic component is the 1st type of collagen. Furthermore, after oozing of the lytical enzymes and ceasing of the chemical bonds, the changes take place in the organic matrix of bone tissues as well. Initially, the changes occur in the organization of collagen, the chains of amino acids loosen (relax) and the fibrils lose their normal length, at the same time widening their diameter. Then comes uncoiling of the chain and formation of a gelatin type mass and, finally, overall decomposition of collagen takes place. Previously mentioned changes give us possibility to think about decrease of anisotropy of the extracellular matrix. The changes cause in the structure and composition of mineral substances as well. In presence of physiological circumstances (adequate blood flow, loading) there is a consequent balance of Ca level between soluble Ca and phosphorus in the intra - cellular space of bone tissues and mineralization of collagen takes place as well. In the event of entire interruption of blood flow, the dysfunctions of interchange of mineral substances take place. Due to entire interruption of blood flow in the amputated part, an active movement or exchange of mineral substances of bone tissues with the help of blood or tissues liquid is not possible. As a result of the above mentioned processes of organic and non-organic parts of bone tissues, the changes occur in the structural organization of bone tissues and thus the increase of UV in bone tissues, observed in the investigation, could be explained.

As a rule, in case of replantation, when, after a long time ischemia, the blood flow is restored an essential oedema is observed. As more a long time of ischemia as longer and more visible oedema could be observes in soft tissues which are connected with damaging of tissues caused by reperfusion. With the increase of oedema, Cleland`s bands increase the disorder of extra-osseus venous congestion because of compression of the subcutaneous veins. Disturbances in the venous outflow can develop disorder of microcirculation in the early postreplantation period. In fact, the significance of this anatomical peculiarity in case of replantation is rarely mentioned by authors nevertheless there are some clinical occasions described.

Several authors point out that in case of replantation of finger followed by subcutaneous venous thrombosis, the arteries are endangered of thrombosis as well, although the arterial thrombosis does not occur at once. According to the data arterial blood flow continues in the replantated part for some hour or sometimes one or two days after venous thrombosis happened and it is possible to detect using doplerography. Only possibility to deponating blood in the bone could explain situation when venous outflow is closed but arterial blood flow continues. This power of bone tissues deponating the blood could act as a compensation mechanism. In condition of venous stasis, the intra-osseus pressure in the bone increases slowly and while the decompensation of intra-osseus blood flow does not occur, the extra-osseus arterial blood flow is possible. That is approving importance of bone condition in the venous outflow realization in the amputated part. The results of some investigations gives us possibility to conclude that intra-osseous venous blood flow is very important in the venous congestion situation and showed that it can be most important for compensation and survival of the replantated part. At the time of replantation good osteosynthesis with bone ends located as closely as possible could give possibility for venous outflow in the early postreplantation time. The results of several authors showed blood flow as a sign of venous outflow in the arthrodesis proximal part as leak of contrast in the early postoperative time. The irreversible changes caused by a long time ischemia in bone tissues of the amputated part could disturb intra-osseous venous blood flow as a compensatory mechanism. If the changes in bone tissues before the restoration of blood flow have become irreversible due to a long time ischemia, then, in case of venous stasis the bone tissues cannot participate in above mentioned mechanism of compensation.

The changes caused by a long time ischemia in bone tissues of the amputated part could affect the possible outcome of replantation in two ways. Firstly, they can participate in provision of venous congestion at early period of replantation. Secondly, the condition of bone tissues at later period provides early opportunities of rehabilitation which is the first prerequisite for recovering the function of the replanted part. After the long time ischemia compensation can be reached but function of the replantated part can be poor. Bone viability is the main thing.

It is important to treat bone tissues with all possible care during the operation excluding the drying up of bone tissues as well as, using the saw, to avoid „scorching” of ends of bones which could arise as a result of high attrition. Furthermore, it is significant to place the ends of bones as precisely against each other as possible and, performing the osteosynthesis, to apply the methods which damage the bones as least as possible.

At present it is proved that early rehabilitation and development of movements essentially improve the condition of entire structure and reduce the risk of oedema in the replanted part as well as scar tissue formation which in turn reduce the tendon adhesion and stiffness of joints. The main aim of replantation is to restore the functionality of the replanted part. Replantation is controvertible if result will not

reach aim. The exception is amputation in children and amputation of distal phalanges of the finger. The early rehabilitation is not possible in cases when a stable osteosynthesis had not been performed or consolidation is not happening. Besides, a long, entire immobilization of member or its part reduces the density of bones but the porosity of cortical bone increases. At the same time the mass of glikozaminoligans (glucosamine) and collagen reduces. There are investigations which prove that in the result of immobilization essential changes arise in that part of bone where the links of joints are fixed. Moreover, the changes are observed in the structure of tendons and cartilage as well. At the same time, too early fulfillment of movements could cause disorder of consolidation of the bone and increase the amount of scar tissue formation in muscles. Therefore initially it is advisable to respect a short period of entire rest-cure and start a gradual, passive and then active development of movements later. At early period of post replantation the passive range of movements are mostly used but active movements advisable then after. All kind of movements and loading could be started only after satisfactory consolidation of bones. The speed of consolidation depends on condition of bones which in turn is determined by condition and viability of bone tissues of amputated part. In fact, quite often the complications connected with the condition of bone tissues could be beholden only after beginning of active rehabilitation.

According to the data in literature there are several investigations performed and clinical cases described which the changes in bones explain by development of venous congestion and the processes that follow it. A long time ischemia which causes essential and, possibly, irreversible changes in bone tissues combined with other factors could cause disorder of arterial blood flow and could provoke slowdown or even lack of consolidation process of bones or other complications. Summing up the data of literature and the results of the performed investigation it is possible to establish regularities which we have combined in scheme showing the homeostasis of the replanted part (Fig.15.).

## Homeostasis of replantated part

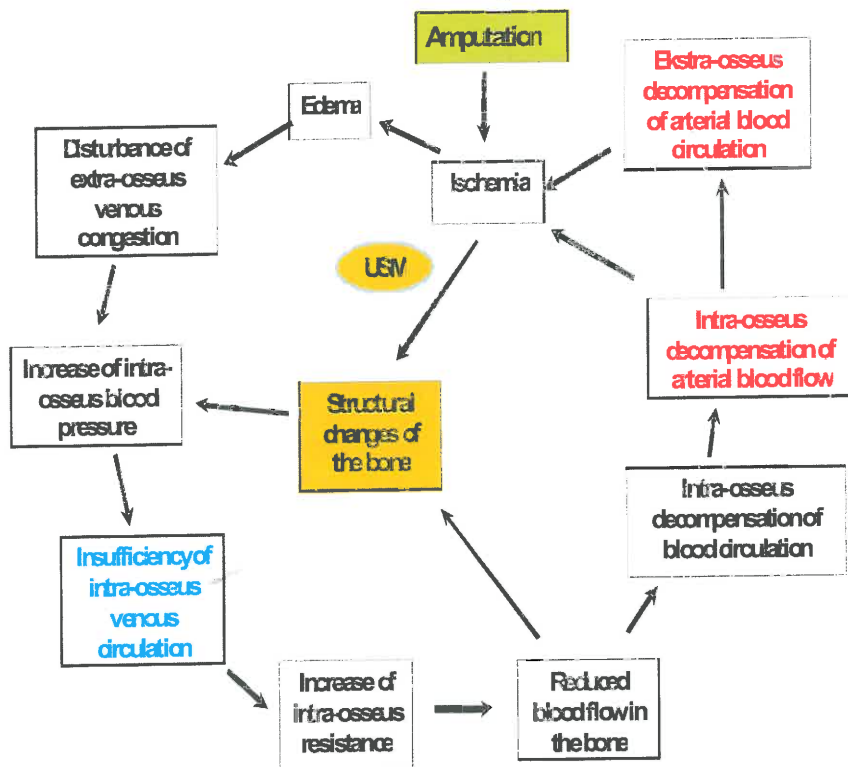


Fig.15. Homeostasis of replantated part.



Successful restoration of blood circulation in soft tissues of the amputated part must be done at first and that is very important. However, as result of some factors venous congestion of replantated part could happen and intra-osseous and then after extra-osseous arterial insufficiency could develop. That could develop deeper, structural changes of bone because of ischemia. Bone condition before replantation is very important at that point. If circulation in the replantated part however compensate there is high risk of disorder of bone consolidation which prohibit early rehabilitation and long time result will be stiffness of the joint and more or less poor function. If circulation in the replantated part will not compensate then necrosis will develop and it's mean that good restoration of blood circulation in soft tissue at the beginning could end with non-functional finger or part of extremity.

Possibility to detect changes in the bone due to the long time of ischemia gives chance to predict bone tissue condition and possible functional result of replantated part as well as help to predict development of complications, mostly venous congestion development.

Damages because of long time of ischemia

### 10. Conclusions

1. Changes of bone tissue caused by a long time ischemia in amputated parts can be detect using ultrasonometry (USM).
2. In experimental study ultrasound velocity changes have been detected in amputated parts bone tissue after a long time ischemia:
  - a slight rise (5,4%) of ultrasound velocity has been detected after 3 hours of blood circulation interruption already,
  - maximum (10,8%) increase of ultrasound velocity has been established 17 hours later after interruption of blood flow.
3. Ultrasound velocity in amputated parts bone tissue increases comparatively to the healthy part bone tissue.
4. Ultrasound velocity in the amputated parts bone increase depends on length of ischemia:
  - if ischemia time is not longer than 5 hour increase of UV is 11%
  - if ischemia time is more than 5hour - UV increase will be 30%.
5. Ultrasound velocity in amputated parts does not depend on patient's sex, hand dominance and age.
6. Amputated part bone tissue changes could promote venous congestion development in the replanted part and cause blood circulation decompensation in the replantated part.
7. There have been developed recommendation to reduce venous stasis appearance in replantated parts.

## 11. Recommendations

1. Potentially decrease time of ischemia of amputated segment before replantation.
2. Place the amputated part in cool (0 - 4C°), dry place, so it must not get wet or float in a water.
3. In the case of a long time ischemia in amputated part to evaluate a necessity to provide dissection of fascia and separate bands (e.g. Grayson's & Cleland's bands in finger) in order to prevent development of compartment syndrome, including in fingers distally from the MCP joints.
4. During replantation it is necessary to provide osteosynthesis in less traumatic way to protect bone from damage and also avoid from a venous blood flow disruptions in replantated parts, including venous flow paths of bones:
  - osteosynthesis should be provided in most stable way as possible,
  - detachment of periosteum in a broad area should be avoided,
  - a bone ends should be located as closely as possible in the site of osteosynthesis,
  - fixation through a bone located distally from replantation level should be avoided,
  - during osteosynthesis it's significant to avoid from inserting the wire or screws through the ends of phalanges (epiphysis, metaphysis),
  - entering the wire it should be projected as parallel as possible to the long axis of a bone,
  - if in the correction of the bone length or shape a saw is used, it is significant to provide a tissue cooling at the same time (eg, using NaCl 0.9%),
  - exposure time during surgery should be reduced in order to prevent bone from drying.
5. In the early postoperative period after the replantation patient is recommended to elevate hand to reduce edema and to ensure optimal venous blood circulation – suggested posture is raised arm and hand resting on the head, thus creating a space for free flow. The tactic recommended above can only be used if there is no venous flow disturbing factors, such as tight dressing gauze.
6. For replantated extremity it is significant to provide early range of motion as soon as possible, thus promoting venous flow too. Range of motion should be started using large joints first – the shoulder, elbow joint, then wrist and finger joints.

7. In the early postoperative period immobilization is usually used. It is significant that immobilization is used only for as few joints as possible. In order to avoid muscle contracture and venous stasis it is essential to perform regular hand exercises.
8. Attention should be paid to dressing gauze to avoid to apply it too tight.
9. Replanted part should not be exposed to heat but be ensured that for patients whole body temperature is comfortable (for vascular lumen body temperature is the best that provide relaxation).

## 12. Publications on the study team

L.Logina, D.Krieviņš "Totāli vai subtotāli amputētu pirkstu lokālā stāvokļa izvērtēšana iespējamai replantācijai" RSU Zinātniskie raksti Rīga, 2008: 149-151.

L.Logina, D.Krieviņš, K.Drevinska, R.Auzāns (RSU) "Pirmie eksperimentālie rezultāti kaulaudu akustisko īpašību izmaiņu diagnostikā pēc asinsrites pārtraukšanas" RSU Zinātniskie raksti; Rīga, 2009: 195-200.

L.Logina, D.Krievins, A.Timuhins „First results of the bone ultrasound measurements after the upper limb replantation and multilated trauma” Proceedings of the XV Congress of the FESSH, Medimond S.r.l., Monduzzi Editore International Proceedings Medimond Publisher (Raksts ir pieņemts, bet nav zināmas konkrētas lapas puses, iznāks līdz 2010.06.20.)

Handed in:

L.Logina, D.Krievins, K.Drevinska, R.Auzans, A.Timuhins, L.Svabe, „Ultrasound velocity in bone after acute disruption of blood circulation” Latvian Journal of Physics and Technical Sciences

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Publications related to the study

A.Vētra, An.Vētra, V.Logins, L.Logina "Changes of the bone acoustic properties in the hemiplegic patients at the period of rehabilitation." RSU scientific works, 2002, 2, pp. 32-38.

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L.Logina, D.Krievins (RSU) "Assessment of the total or subtotal amputated part of the digit for the possible replantation". XIVth Congress of The Federation of European Societies of Surgery of the Hand (Poznan, Poland, 3-6, 2009.)

L.Logina, D.Krievins (RSU) "Replantation of the fingers in Latvia – first study of five year period". XIVth Congress of The Federation of European Societies of Surgery of the Hand (Poznan, Poland, 3-6, 2009.)

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L.Logina, D.Krievins, A.Timuhins "First results of ultrasound velocity changes through the bones of phalanges of the amputated part after the long ischemia" – The 1<sup>st</sup> Baltic Hand Surgery Meeting (Riga, Latvia, May 24-25, 2010)

L.Logina, D.Krieviņš „First results of the bone ultrasound measurements after the upper limb replantation and multilated trauma” XVth Congress of The Federation of European Societies of Surgery of the Hand (Rumānija, Bukareste, 2010., 23-26.jūnijs)

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L.Logina Plastic, reconstructive, hand and microsurgery in Latvia  
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L.Logina, D.Krievins, A.Timuhins "First results of ultrasound velocity  
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ischemia" – Mutiska uzstāšanās The 1<sup>st</sup> Baltic Hand Surgery Meeting (Riga,  
Latvia, May 24-25, 2010)

L.Logina, D.Krieviņš „First results of the bone ultrasound  
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referāts XVth Congress of The Federation of European Societies of Surgery of  
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