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A comparison between three irrigation methods in the debridement of contaminated bovine cancellous bone and the effect of duration of irrigation on the efficiency of debridement

Kirletilmiş dana spongiöz kemiğinin debridmanında üç yıkama yönteminin karşılaştırılması ve yıkama süresinin debridman üzerine etkisi

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Amaç: Açık kırıklarda yıkama ve debridman, tedavinin önemli bir bölümünü oluşturur. Bu çalışmada, farklı yıkama yöntemlerinin ve farklı sürelerde yıkamanın kirletilmiş sığır femur spongiöz kemik örneklerinin temizlenmesindeki etkinliği ve yıkamaya bağlı oluşabilecek kemik hasarı araştırıldı.

Çalışma planı: Taze donmuş sığır distal femurundan 4x4x1 cm boyutlarında 72 adet spongiöz kemik örneği alındı ve her bir örneğin üst yüzeyi 2 mm derinliğinde oyularak eşit büyüklükte dört kare oluşturuldu. Bütün kemikler aynı yöntem kullanılarak inşaat kumu ile kirletildi. Örneklerden rastgele seçimle 24 adetlik üç grup oluşturuldu. Bir gruba 20 ml'lik plastik şırınga ile yıkama uygulanırken, bir gruba düşük basınçlı (DBY), bir gruba yüksek basınçlı (YBY) yıkama uygulandı. Yıkama her bir gruptaki sekizer örneğe farklı sürelerde (3, 6 ve 9 dakika) uygulandı. Yıkama işleminden sonra kemik örneklerinin görüntüleri video-mikroskop kamera ile bilgisayar ekranına aktarılarak üzerinde kalan kum tanecikleri sayıldı ve yıkama sonrası kemikte oluşan makroskobik doku hasarı değerlendirildi.

Sonuçlar: Yüksek basınçlı yıkama uygulanan örneklerde, diğer iki yönteme göre anlamlı derecede düşük sayıda kum taneciği bulundu ($p<0.001$). Hiçbir grupta farklı sürelerde yıkamanın (3, 6 ve 9 dk) debridman üzerinde anlamlı etkisi görülmedi ($p>0.05$). Yıkama sonucu kemikte en az doku hasarı 3 dk'lık yıkamada DBY yönteminde görüldü ($p<0.01$). Daha uzun süreli yıkamalarda ise kemik hasarı üç yöntemde de benzer idi ($p>0.05$).

Çıkarımlar: Bulgularımız, kum taneciklerinin temizlenmesinde en etkili yöntemin YBY olduğunu ve yıkama süresini artırmanın ek yarar sağlamadığını; ancak, YBY yönteminin 3 dakikalık yıkamada kemik dokusuna en fazla zarar veren yöntem olduğunu göstermiştir.

Anahtar sözcükler: Debridman; kırık iyileşmesi; irigasyon/yöntem; basınç; yara enfeksiyonu/önleme ve kontrol.

Objectives: Irrigation and debridement constitute an important part of treatment of open fractures. We investigated the efficiency of different irrigation methods and durations in cleansing contaminated bovine femur cancellous bone samples and the extent of tissue damage associated with irrigation.

Methods: A total of 72 samples of 4x4x1 cm size were obtained from fresh frozen bovine distal femoral cancellous bone. The top surface of the samples were sawed to a 2-mm depth to create four squares equal in size. All the samples were contaminated with construction sand using the same method and were then randomized to three irrigation groups (bulb syringe irrigation, high-pressure pulsatile lavage, and low-pressure pulsatile lavage), each consisting of 24 samples. The duration of irrigation was set as 3, 6, or 9 minutes for every eight samples of each group. After the irrigation procedure, the images were transferred to a computer screen with a video-microscope camera and the number of sand particles on the samples were counted and irrigation-related macroscopic bone damage was assessed.

Results: The lowest number of sand particles was found on the samples irrigated by high-pressure pulsatile lavage ($p<0.001$). The duration of irrigation did not affect the efficiency of cleansing in all the groups ($p>0.05$). The least irrigation-related bone damage was observed in samples irrigated by low-pressure pulsatile lavage for 3 minutes ($p<0.01$). The amount of bone damage was similar in all groups after irrigations beyond 3 minutes ($p>0.05$).

Conclusion: Our findings showed that the most efficient method of cleansing contaminated bone samples was high-pressure pulsatile lavage and that prolonged irrigations did not enhance the efficiency of the irrigation method; however, high-pressure irrigation of 3 minute duration resulted in the greatest bone damage.

Key words: Debridement; fracture healing; irrigation/methods; pressure; wound infection/prevention & control.

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Wound irrigation and debridement of non-viable tissues in open extremity trauma are the most important steps in treatment. During debridement, it is also necessary to choose a method that does less harm to the living tissues.[1, 2, 3] In previous years, this irrigation procedure which was performed using syringes, has now been replaced by high pressure irrigation systems in total joint arthroplasty, effectively removes the debris and free bone particles located in bone medulla. A method depending on this mehanism has taken the place of another irrigation method that is performed using the DeLee suction catheter and syringe in open extremity trauma. Recent studies have shown that these high pressure irrigation systems are very effective in ridding the contaminated bone and soft tissues of foreign particles and also in decreasing the soft tissue infection rates.[4, 5, 6, 7, 8] Beside this, there are studies that have mentioned that these systems are not as innocent as they may have seemed to be, and that these systems may result in damage to the soft tissues and bones in the irrigated wound.[9, 10, 11, 12, 13] Furthermore, the irrigation times were generally kept constant in the studies that compared different irrigation systems.[11, 13] In this study our purpose is to determine the most efficient irrigation method which produce we least damage in the bone depending on the irrigation time for debridement of contaminated bovine cancellous bone.

Material and method

Test groups

Distal femurs of calf used in the study were purchased from the butcher and kept in the refrigerator at -4° C. On the day of the experiment, the calf distal femurs were cut into 4x4x1 cm-sized pieces by an electric bone saw and 72 test samples were prepared. Then, the superior surface of these test samples were cut into 2 cm depth by electric saw and 2x2-sized cubes were produced (Figure 1).

Contamination procedure of test samples

The test sample bone was placed in a plastic box 20 cm in length, 13 cm in width and 10 cm in depth. The box was closed following placing 20cc of construction sand in it and the box was shaken for 3 minutes in a rhythmic manner. Contamination of the test bone samples with construction sand were applied to all test samples by the same standard procedure. These contaminated test samples were randomly divided into 3 groups, each containing 24 pieces. The first group was named the plastic syringe irrigation group, the second was named LPL, and the third group was named HPL.

Irrigation procedure

Each group comprised 24 bones following contamination, were irrigated with physiological serum for 3 min., 6 min. and 9 min. Contaminated bone samples were irrigated using different irrigation methods which had been situated 10 cm away from the samples perpendicularly. Irrigation methods were composed of plastic syringe (20cc Hayat, Çorum Türkiye) (syringe pressure was estimated by Rodeheaver et al.[7] nearly 1-2 psi), DBY (<15 psi) (Simpulse ® Varicare System, Davol, Inc. US.), which had double-water inward and working with two batteries and YBY, which could be assembled to rechargeable battery system (Interpulse irrigation system; Stryker Instruments, Kalamazoo, MI, US).

Evaluation of test samples after irrigation procedure

The efficacy of debridement was evaluated quantitively. Quantitive evaluation was performed by counting the retained construction sand particles on the test sample bone surfaces after debridement. This counting procedure was done by the help of a USB digital microscope (Digimicro 1.3 mega pixel digital camera, magnification rate10x to 200x, PRC) (Figure 2). Images of scanned bone surfaces were transfered to the computer through a USB cable and construction sand particles on each bone surface were counted (Figure 3).

Figure 1. The apperance of bone sample in 4x4x1 sizes prepared from calf femur spongious bone for the irrigation experiment.

Table 1. Qualitative evaluation scala of macroscopic cancellous bone damage

Group	Qualitative macroscopic tissue damage grading scala
1	No damage in the bone tissue. • No disturbance of organic material between the cancellous bone trabeculae The space between cancellous bone is full of organic material.
2	Minimal damage in bone architecture (between group1 and 3).
3	Intermediate damage on bone surface. • Intermediately disturbed organic material between trabeculae, but limited damage on bone surface. • Still clear apperance of bone cells after cutting.
4	Intermediate damage in bone (between group 3 and 5).
5	Severe damage in bone. • Even the organic material in the cell borders between trabecula was disturbed. • Difficulty in differentiating the borders of cells.

In order to evaluate the damage on the bone surfaces after irrigation, "Qualitative macroscopic tissue damage grading scale", which was used by Draeger et al. [11], was also used in our study (Table 1). Test sample bones which were debrided, were evaluated by a specialist doctor with the help of the same digital microscope.

Data analysis

The obtained results were summarized by descriptive statistics (Median, minimum, maximum, mean, standard deviation). The tissue damage grading scores and the number of retained construction sand particles in bones were analysed between the groups and within groups by the Kruskal-Wallis (and then post-hoc Mann Whitney test) and the Freidman tests. All statistical analyses were performed by the help of the SPSS 16.00 computer programme.

Results

The test samples irrigated by HPL had a statistically significant lower number of construction sand particles than the LPL and the syringe group when irrigated for 3, 6 and 9 minutes ($P<0.001$) (Figure 4). When the Friedman test was used for evaluation of irrigation times within the HPL group, it was seen that neither of the irrigations at 3., 6., or the 9. minutes

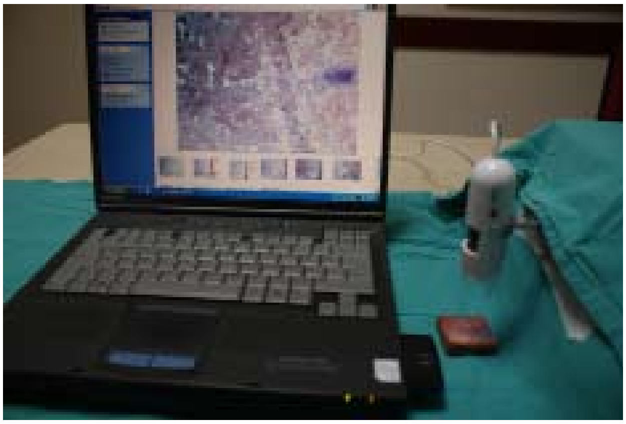

Figure 2. The apperance of connection of video-microscope to the computer, which was used for the counting of sand particles over the spongious bone surface in irrigation experiment.

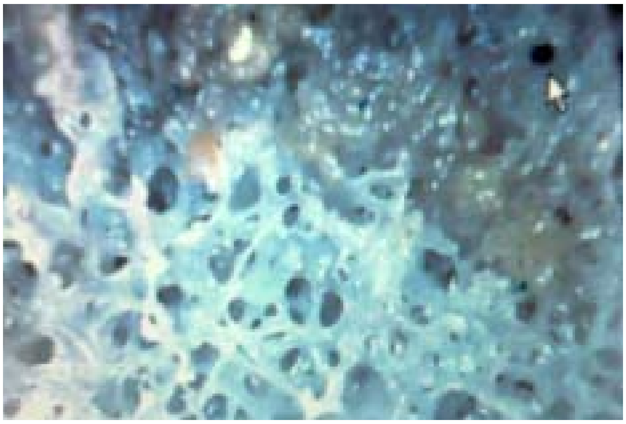

Figure 3. The apperance of sand particles (arrow) under video-microscope enlargement after irrigation

had superiority over each other ($p>0.05$). According to these results, it was concluded that HPL is the most effective method for the debridement of contaminated bone samples, and that lengthening of the irrigation time is unnecessary and 3 minutes irrigation is sufficient for the debridement.

In the evaluation of tissue damage in bone due to irrigation (Table 2), it was seen that bone damage was minimum in 3-minute irrigation by LPL ($p<0.01$); these damages were similar to other irrigation methods, and bone damage in all irrigation methods for 6 and 9 minutes were similar ($p>0.05$). According to these findings, we concluded that a long irrigation time led to damage of the bones and that this damage was unrelated to the irrigation method.

Discussion

The aim in open fractures is to prevent hospital infections, to induce fracture healing and to support

Table 2. Distribution of irrigation samples according to the qualitative macroscopic tissue damage evaluation

	1. sample	2. sample	3. sample	4. sample	5. sample	6. sample	7. sample	8. sample
3. minute								
Bulb syringe	2	2	2	3	1	2	1	2
Low pressure lavage	2	1	2	1	2	2	2	2
High pressure lavage	3	4	3	3	2	3	2	3
6. minute								
Bulb syringe	3	3	2	2	2	3	2	3
Low pressure lavage	1	3	2	3	2	2	1	3
High pressure lavage	4	3	3	4	3	3	3	4
9. minute								
Bulb syringe	2	3	3	1	2	3	2	3
Low pressure lavage	4	4	3	3	2	2	3	4
High pressure lavage	4	3	4	3	3	4	3	4

the patient in returning to his/her previous activities. The primary treatment of an open fracture and contaminated soft tissue damage after trauma is debridement of the contaminated bones.[9, 14, 15, 16, 17] Although the value of antiseptic irrigation solutions and local antibiotics have been demonstrated [6, 18, 19] , it has been emphasized that effectiveness of mechanical irrigation is more important than antimicrobial solutions.[20]

For this reason, different irrigation methods are being used now. In this in-vitro study, contaminated calf bones were irrigated by different techniques in different periods. The efficacy of the irrigation methods and irrigation periods, and the grades of bone damage occurring due to the irrigation method were evaluated.

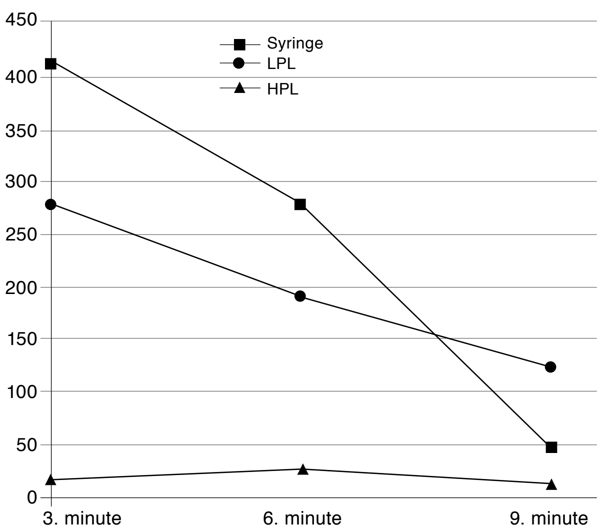

Figure 4. Graphical distribution of the counted number of particles of contaminated spongious bone samples by video-microscope after different irrigation methods and different time periods

Although there is not a consesus up to date, there are some articals which take 35-70 psi pressure irrigation as HPL, and 1-15 psi irrigation as LPL[21] where as there are also others taking 8,8 psi pressure lavage as HPL.[22] There have been several studies on the widespread testing of high pressure irrigation systems in contaminated soft tissue debridement.[6, 9, 21, 22, 23, 24] The beneficial effects of these high pressure irrigation systems in bone tissue debridement have been shown.[12, 25, 26] With the help of these proven beneficial effects, these systems have become the standard method for the debridement of open fractures and contaminated soft tissue wounds, and have come to be used frequently in clinical practice.

In this study, irrigation methods in contaminated bone debridement and results of counting the number of construction sand particles on the bone after irrigation using video-microscopy, were evaluated. According to these results, it was concluded that HPL was the most effective method for the debridement of contaminated bone samples, and that lengthening of the irrigation time was unnecessary, and 3 minutes of irrigation was sufficient for the debridement.

Although there have been studies stating that there is no difference between the results of debridement of contaminated tissues by HPL system and LPL or syringe,[11, 12, 13] there have been studies mentioning that HPL is more effective than LPL and classical irrigation systems in removal of foreign particles.[5, 22, 27, 28] Hamer et al. [22] have shown that HPL (50 psi) is more effective than irrigation with syringe in removing the bacteria from the contaminated wounds of rats. In a similar study, Brown et al.[5] showed that HPL (50 psi) was more effective than the other irrigation methods in irrigation of the wounds. Svoboda et al. [24] found that HPL (19 psi) was more effective than irrigation with syringe in removal of bacteria from contaminated complex wounds that were created in goats. Showing the efficacy of HPL on the soft tissue damage has led to a reality that this irrigation method had to be evaluated in bones. Draeger et al. reported that HPL (19 psi) was more effective than syringe (1-2 psi) and brush irrigation system in removing organic particles from the bone; however, for removal of inorganic contaminants, the syringe and brush system were seen to remove a more statistically significant amount of inorganic contaminant; there was no statistically significant difference in removal of inorganic contaminants between HPL and syringe and brush system. It has been suggested that irrigation with brush could be an alternative for high pressure irrigation in traumatic open fractures due to the high bone damage in the HPL system. Lee et al.[12] reported that both HPL(70 psi) and syringe irrigation had cleared the graphite contaminant from the metaphysis spongious bone similarly in a rabbit femur fracture model, and observed more bone damage in the HPL method. Hirn et al.[25] showed in the bacterial cleansing of allografts that the HPL (6 psi) system was more effective than the methods that included keeping the allograft in physiological serum for 30 minutes and having the allograft wait in the physiological serum with antibiotics.

Some concern has arisen [6, 8, 29, 30], as it has been shown that damage in soft tissues and bones had occurred during debridement in the experimental studies, against this irrigation sytem which had been shown that it had been effective in decreasing the particle number and infection rate in the contaminated soft tissues.[5, 6, 8] Wheeler et.al.[8] showed that pulsative irrigation systems decreased the resistance of the wound against infection. They thought that this had occured because the administered liquid had penetrated to 14 mm depth of the tissues. Byod et al. [31] mentioned that high pressure irrigation systems (35-70 psi) had led to deeper penetration than the low pressure systems (3 psi), and made prominent damage in soft tissues. Hassinger et al. [32] showed that high pressure irrigation systems had resulted in deeper bacterial penetration into soft tissues than the low pressure systems and resulted in more bacterial retention in the soft tissues. The effects on bones were evaluated following investigation of these undesired effects of irrigation systems in soft tissues. Bhandari et al.[10] reported that bone structure damage had been observed more prominently in the fracture line and progressively decreased bone structure damage when going away from the fracture site. Meanwhile, these irrigation systems had led to spreading of bacteria to a 4cm depth at the fracture site. Again, Bhandari et al.[29] showed that low pressure irrigation systems were as effective as the high pressure irrigation systems in removing Staphhlococcus aureus during the debridement of contaminated tibial fractures, but the high pressure system made more extensive tissue structural damage when evaluated according to tissue damage. Dirschl et al.[30] reported that high pressure irrigation that it gives harm to early bone healing intraarticular fracture modal. According to this result, it was seen that new bone formation had decreased in the control group and significantly less viable bone had been found in the fracture site. In the study of Draeger et al. [11], it was shown that high pressure irrigation system (19 psi) had led to more damage in bone marrow than the low pressure irrigation system. This was shown by measuring the organic contaminant obtained from the irrigated bone samples. Polzin et al. [33] reported that high pressure irrigation systems (50 psi and over) had led to the appearance of cellular material from the irrigation area and by this way, new bone formation was inhibited in the fracture site. It has been mentioned that orthopedics surgeons must keep in mind that there is a risk of damage occurance in the fracture site when it is irrigated with a pressure of 50psi or over.

In our study, damage in bone tissue during debridement was shown macroscopically and with the help of video-microscopy. According to this, it was seen that bone damage was least in 3 minute irrigation by LPL ($p<0.01$), and although the most damage was seen in the HPL group, there was no significant difference when compared with syringe irrigation.

The higest degree of bone damage seen during the bone debridement in our study belonged to the HPL system. This result was in paralel with that of the literature. Bone damage was seen to be similar in each method for 6 and 9 minute irrigation ($p>0.05$). From that point of view, we reached a result that whichever method had been used, the long time irrigation resulted in inevitable bone damage.

We thought that there were some limiting factors in our in-vitro study. Due to the fact that the used tissue samples in the study were obtained from the calf distal femur, the difference between the properties of non-viable and viable tissues could affect the evaluation of qualitative tissue damage. The other limiting factor may be the method used in evalauting the qualitative tissue measurement. According to the scala mentioned by Drager et al.[11] there may be differences between individuals or within the people in the evaluation. The other limiting factor may be the method of bone contamination. We only used construction sand for contamination, and no other contamination material was used. However, bone may be contaminated with organic and inorganic materials in open fractures. The debridement of these wounds may not be easy as in our study.

In summary, it was shown that HPL is superior to the syringe method in soft tissue debridement and this method is used widely in irrigation of open fractures. But this superiority was kept in the background of the information which stated that more tissue damage was seen in HPL. After demonstrating the undesired side effects as a result of HPL in bone tissue in several studies, some drawbacks regarding the HPL irrigation has occured. In this study, similar results to those of the literature were obtained. Although particles were mostly debrided by HPL, most tissue damage was seen in this method again. Accoring to these results, additional studies are needed for developing irrigation methods which would decrease the structural damages during tissue debridement. It may be that studies about determining the optimal pressure level that decrease the structural tissue damage to the lowest level during irrigation with pressure systems would be beneficial and these results would lead to susbtantial development in debridement of complex muscle skeletal system damages.

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