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The factors affecting thermal necrosis secondary to the application of the Ilizarov transosseous wire

Ilizarov transosseöz telin kemikten geçirilmesine bağlı oluşan termal nekrozu etkileyen faktörler

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Amaç: Ilizarov transosseöz telin (TT) kemikten geçirilmesi sırasında ortaya çıkan ısı değişimleri, buna bağlı oluşan nekroz ve bunu etkileyen faktörler deneysel olarak araştırıldı.

Çalışma planı: Bir yaşındaki bir dananın iki tibiasının metafiz bölgeleri çıkartıldıktan sonra diafiz kısımları üzerinde dört eşit bölge işaretlendi. Her bölge ve devir (600, 900, 1200 ve 1800 devir/dk) için ayrı bir TT kullanıldı. Telin korteksten geçirilmesi sırasında oluşan ısı değişimleri elektrotlarla kaydedildi ve TT'nin ilerleme hızı ölçüldü. Histopatolojik inceleme için telin giriş ve çıkış bölgelerinden örnekler alınarak nekroz oluşan bölgelerin kalınlıkları ölçüldü. Bölgeler ve yakın ve uzak korteksler arasındaki ısı değişimleri karşılaştırıldı. Isı değişimini etkileyen en önemli etkenin belirlenmesi için lineer regresyon analizi kullanıldı.

Sonuçlar: Uygulama sırasında oluşan ısı 48.4 °C (1200 devirde) ile 151.9 °C (600 devirde) arasında dağılım gösterdi. Yakın korteksin kalınlığı, tel geçiş süresi ve hızı açısından bölgeler arasında anlamlı farklılık bulundu (sırasıyla, p=0.003, p=0.01 ve p=0.01). Telin devir hızı ile nekroz alanı kalınlığı arasında negatif korelasyon görüldü (r=-0.901, p=0.001). Regresyon analizinde, yakın ve uzak kortekste ısı oluşumunu belirleyen en önemli etken, telin korteksi geçiş süresi olarak belirlendi (sırasıyla, p=0.001 ve p=0.003). Histopatolojik incelemede, telin devir hızının düşük olduğu bölgelerde nekroz alanı ve kemik erozyonu daha fazlaydı. Yakın korteksteki nekroz alanı uzak kortekse göre anlamlı derecede fazlaydı (p=0.006).

Çıkarımlar: Termal nekrozu azaltmak için TT'yi korteksten yüksek devir hızında ve mümkün olan en kısa sürede geçirmek gerekir.

Anahtar sözcükler: Kemik teli; büyükbaş hayvan; kırık fiksasyonu/yöntem; ısı/yan etki; Ilizarov tekniği; nekroz; termodinami; tibia; zaman faktörü.

Objectives: We investigated thermal changes associated with the application of the Ilizarov transosseous wires, the extent of necrosis and the factors affecting necrosis.

Methods: We used a pair of tibiae from a 1-year-old cow. After removal of metaphyseal areas, each of four equal diaphyseal zones marked on both tibiae was drilled at 600, 900, 1,200 and 1,800 rpm, each time with a new wire. Heat changes were recorded with heat electrodes during the application and the speed of the wire was calculated. For histopathological examination, specimens were obtained at the access and exit sites to assess the extent of necrosis. Thermal changes between the zones and immediate and remote cortices were compared. The most significant factor affecting the heat changes was analyzed by linear regression.

Results: Heat changes varied between 48.4 °C (at 1,200 rpm) and 151.9 °C (at 600 rpm). The thickness of the immediate cortex, the time and speed for the wire to pass the cortex were found as significant parameters in heat changes (p=0.003, p=0.01, and p=0.01, respectively). A negative correlation was found between the speed of the wire and the thickness of the necrotic area (r=-0.901, p=0.001). Regression analysis showed that the time for the wire to pass through the cortex was the most significant factor in inducing heat changes in both cortices (p=0.001, p=0.003, respectively). Histopathologically, the extent of necrosis and bone erosion was associated with lower drill speeds. Necrosis was significantly notable in the immediate cortex than that of the remote one (p=0.006).

Conclusion: Transosseous wires should be passed at high drill speeds and with earliest time elapses to reduce thermal necrosis.

Key words: Bone wires; cattle; fracture fixation/methods; heat/ adverse effects; Ilizarov technique; necrosis; thermodynamics; tibia; time factors.

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Several studies investigated the thermal changes occurring while drill bits, Kirchner wires and various nails are advanced through the bone.[1-7] It has been demonstrated that use of high-speed drill leads to necrosis; and this effect is much lesser with low-speed manual drills.[8] Other factors affecting the extent of the thermal necrosis include cortical thickness of the bone, shape of the wire's tip and force imposed upon the wire during feeding. In spite of its frequent use during recent years, we couldn't find any study related with the Ilizarov's transosseous wires (TW). The present study experimentally evaluated the relation between the thermal necrosis and its leading factors (cortical thickness, drill speed of the wire, time and speed for the wire to pass from the cortex).

Material and method

We used a pair of tibiae harvested from a one-year old cow. Specimens were transferred to the laboratory inside a special container after the animal was sacrificed. Proximal and distal metaphyseal zones were reamed using a Gigli saw following the removal of soft tissues. The remaining diaphyseal zone was equally divided into four, and surgical intervention sites were marked with a surgical pen (Figure 1). Speed of the drill was adjusted to rotate at 600, 900, 1200 and 1800 revolutions/min before each procedure by means of a stroboscope. The TW chosen had a bayonet tip, and a diameter of 1.8 mm and length of 200 mm.

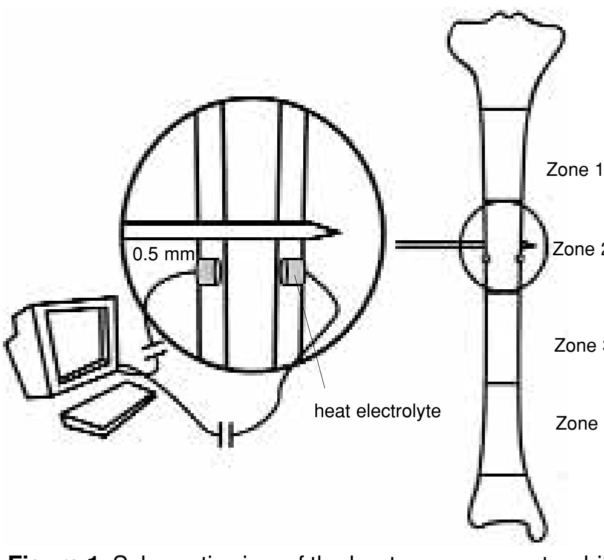

Figure 1. Schematic view of the heat measurements while transosseous wire advances through the bone.

TW was replaced before each drilling procedure. The first and last drilled zones of the bone were called "proximal cortex" and "distal cortex", respectively. Thermocouples (T/C Type T, wire gauge 30) were placed into the two 1 mm holes drilled 0.5 mm distal of the access and exit sites of the wire. Data gathered at each millisecond from these thermocouples were collected on the computer (FLUKE Hydra series-II P/C data collecting unit; reliability±0.2°C). Heat was measured from the time the TW was inserted from the proximal cortex until it left the distal cortex. For each application, heat change graphics were obtained from the computer. A total of eight graphics was prepared, one from each distal and proximal cortex at each zone. This procedure was repeated in cases where there was a problem in the data transfer or where thermocouples were damaged. Procedures were carried out by the same surgeon, and the wire was advanced as fast as possible.

After the heat measurements were completed, 1 cm2 specimen was collected from the access and exit sites of the wire. The cortical thickness of the specimens was measured in mm. And, mean thickness for proximal and distal cortices of each zone was calculated.

Time for the wire to pass the cortex was determined by graphics of the heat changes (Figure 2). For proximal cortex, the time to pass the cortex was determined as the time from the moment the heat starts to elevate until sudden decrease occurs in the heat associated with wire's access into the medullary cavity. The time between the second elevation of heat and termination of measurement was defined as the time to pass the distal cortex.

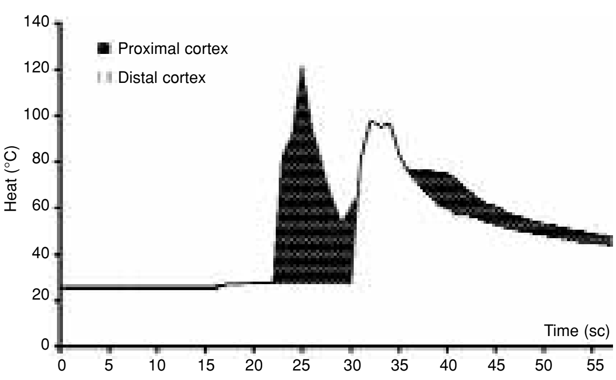

Figure 2. Graphic showing the heat change while transosseous wire advances through the cortices.

Table 1. Rotational speed, time and speed to pass the cortex by zones

	Rotational speed (evolution/min)	Proximal cortex zone I	II	III	IV	Distal cortex zone I	II	III	IV
Time to pass cortex (sec)	600	4.6	6.1	11.0	7.2	4.4	4.8	5.3	5.1
	900	5.6	7.7	9.4	5.5	4.1	6.4	6.0	5.2
	1200	5.4	8.7	9.1	4.7	5.3	7.3	8.3	4.6
	1800	6.2	8.6	8.6	5.2	6.6	6.1	7.2	7.4
Speed to pass cortex (mm/sec)	600	1.25	1.23	0.78	0.76	1.28	1.68	1.51	1.63
	900	0.96	1.01	0.86	0.76	1.26	1.36	1.41	1.58
	1200	1.04	0.91	0.91	0.74	1.04	1.12	1.20	1.74
	1800	0.93	0.90	0.93	0.82	1.02	1.39	1.32	1.20
Temperature (°C)	600	90.7	95.9	151.9	122.7	59.1	59.4	67.3	76.0
	900	97.8	121.3	137.2	74.0	80.3	98.2	65.7	62.1
	1200	85.4	136.0	149.6	69.0	72.7	85.5	98.0	48.4
	1800	134.3	108.7	121.7	105.3	81.7	75.8	67.3	97.9
Necrosis (µm)	600	8	12	13	11	9	20	19	13
	900	9	7	6	7	10	14	14	9
	1200	7	6	7	5	11	9	10	8
	1800	2	5	5	4	7	8	6	7

Wire's speed to pass the cortex (mm/sc) was calculated based on the data on cortical thickness and time to pass the cortex.

For histopathological analysis, bone specimens, which were kept in formaldehyde solution, were embedded in paraffin blocks; and 6 µm sections were cut from those blocks, and stained with hematoxyline-eosine. Thickness of the necrosis around the zone the wire was passing was measured using an ocular micrometer. Mean value was calculated, excluding the values for specimens with the thickest and thinnest necrotic areas (Table 1).

Presence of any heat changes among zones was assessed by variance analysis while Student's t-test was used for comparing the heat changes between the proximal and distal cortices. The most important factor affecting the heat change was determined using the linear regression analysis. $p<0.05$ was considered significant.

Results

Time and speed for the wire to pass the cortex, and temperature and necrosis values are shown at Table 1. The highest heat rate (151.9 °C) was observed in the proximal cortex of zone III at 600 revolutions while the lowest heat rate (48.4 °C) was found in the distal cortex of zone IV at 1200 revolutions. The difference between the temperatures measured in proximal and distal cortices was significant ($p=0.001$). Therefore, all statistical analyses were separately done for proximal and distal cortices (Tables 2 and 3). Significant difference was observed in the proximal cortex in all zones in terms of cortical thickness, time and speed for the wire to pass the cortex ($p=0.003$, $p=0.01$ and $p=0.01$, respectively). In the distal cortex, only cortical thickness was significantly different among the zones ($p=0.02$).

Temperature was defined as the dependent variable in the correlation analysis. Other variables included drill speed of the wire, cortical thickness, time and speed for the wire to pass the cortex and extent of necrosis. Cortical thickness and time for the wire to pass the cortex were the most significant parameters inducing the heat ($p=0.001$). A significant correlation was found between the time and speed to pass the cortex and the heat generation in the distal cortex ($p=0.01$ and $p=0.004$, respectively).

Table 2. Statistical results of variables in proximal and distal cortices by zones

	Proximal cortex		Distal cortex	
	Qui-square	*p*	Qui-square	*p*
Temperature	6.596	0.086	0.838	0.84
Speed to pass cortex	10.929	0.012*	5.716	0.126
Time to pass cortex	11.184	0.011*	3.474	0.324
Cortical thickness	13.636	0.003*	9.098	0.028*
Amount of necrosis	0.31	0.958	1.719	0.633

* Statistically significant.

There was a negative correlation between drill speed and thickness of the necrotic area (r=0.901, p=0.001). A correlation analysis of distal cortex showed that amount of necrosis decreased when the time to pass the cortex was shorter (r=0.793, p=0.001). An analysis using a stepped regression model showed that the most important factor for the heat generation was the time for the wire to pass the cortex (ß=0.84, p=0.001; ß=0.68, p=0.003, respectively).

Histopathological analysis showed that thermal necrotic areas and bone erosion were higher in the passed zones when the drill speed was lower (Figure 3). The amount necrotic area was significantly higher in the proximal cortex compared to the distal cortex (p=0.006). This can be explained with the longer exposure time of the wire with the proximal cortex than with the distal cortex.

Discussion

Use of transosseous wires has been increasing along with the widening scope of the application with external fixator. Those wires are divided into two depending on the shape of their tips; bayonet tip and trocar tip. Trocar tip is frequently used for metaphyseal zones where spongious bones are abundant while bayonet tip is used for diaphyseal bones. They are discriminated mainly to lower the heat generation and avoid thermal necrosis. Bonfield and Li[9] have shown that temperature changes of 50 °C and over irreversibly damaged the collagenous matrix of the bone structure. The high temperature change we measured around 48-152 °C may result from the fact that the cortex of the tibia of the cow was thicker than of human being. However, those outcomes are important in revealing that the temperature can rise too much while advancing the wire through the bone.

Thermal necrosis developing in the bone and the soft tissue may cause loosening of the wire and pin tract infection. A study carried out by electron microscope showed necrosis and loosening around the wire.[10] In order to avoid this, use of a manual drill and cooling solutions have been suggested.[8,11] Two studies reported that drill speed had less effect on the necrotic area,[8,11] which has also been supported by our results.

Toews et al.[6] indicated that cortical thickness and drill speed increased the heat generation and they highlighted the significance of the speed for the

Table 3. Correlation between variables and temperature in the proximal and distal cortices

	Proximal cortex		Distal cortex	
	Correlation coefficient	*p*	Correlation coefficient	*p*
Temperature	0.061	0.823	0.388	0.137
Speed to pass cortex	-0.111	0.684	0.618	0.011*
Time to pass cortex	0.859	0.0001*	0.68	0.004*
Cortical thickness	0.798	0.0001*	0.396	0.129
Amount of necrosis	0.007	0.978	-0.087	0.748

* Statistically significant.

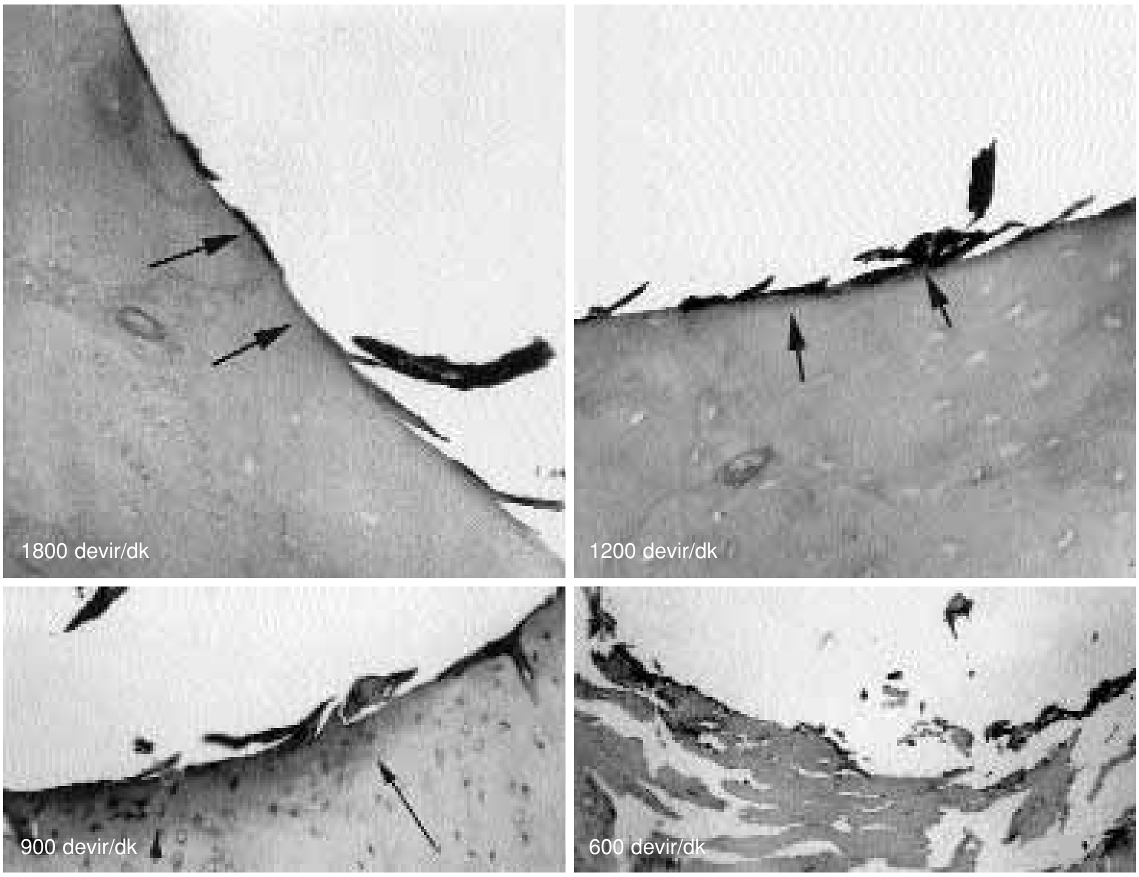

Figure 3. Histological views showing the necrosis at different drill speeds. A small amount of necrosis was observed in the zone where transosseous wire was fed at 1800 revolution/min (shown by arrows) while more crust and necrosis were found in the zone where it was fed at 600 revolution/min (H-E x 100).

wire to pass the cortex in order to reduce the necrotic area. In opposition to this study, we observed that high drill speed and passing the cortex in shorter time reduced the amount of necrosis.

It has been demonstrated that heat generation was elevated in procedures including a force around 4.0 N; but temperature started to decrease due to shorter passing time from the cortex after the force was increased.[2] Another study suggested higher drill speed and application of force for reducing the exposure time of the wire with the bone.[3] We didn't stabilize the force in our study since, in practice, it is not possible to stabilize it during the operation. Furthermore, experience and other interpersonal differences lead to alterations in the force applied while advancing the wire from the cortex.[4]

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