THE EFFECT OF 2-BUTYL-CYANOACRYLATE ADHESIVE IN OSTEOTOMIES AND BONE GRAFTS IN RABBITS: MACROSCOPIC AND RADIOGRAPHIC CHARACTERISTICS

Mário Sérgio Viana Xavier[1], Vilnei Mattioli Leite[2]

ABSTRACT

Objective: To evaluate the effect of butyl-2-cyanoacrylate tissue adhesive in osteotomies and bone grafts, with regard to macroscopic and radiographic characteristics. Methods: Forty-eight rabbits were used, randomly divided into four groups of 12 animals, with observation periods of two, four, eight and 16 weeks. Both thoracic limbs were operated in each animal and two osteotomies were performed in each of the radii, withdrawing a bone fragment (bone graft) of 1 cm in length. On one side, the bone graft was then replaced and a drop of adhesive was applied to each of the osteotomies. On the other side, the same procedure was performed without applying the adhesive. The rejection level for the nullity hypothesis was set at 0.05% or 5%. Results: Blue marks were present in all the surgical specimens in which adhesive was applied. From the fourth week onwards, there was absence of movement of the bone grafts with adhesive and control. In group A, in the proximal osteotomies with adhesive, there was less deviation of the bone graft (p = 0.02). In group C, the union (p = 0.03) and the integration of the bone graft (p = 0.02) were better in the proximal osteotomies with adhesive. Conclusions: The adhesive was not completely metabolized within 16 weeks. There was clinical consolidation of the osteotomies within four weeks. The adhesive stabilized the bone graft within the first weeks and did not interfere with the consolidation of the osteotomies, or the integration of the bone graft in radiographic observations.

Keywords - Tissue Adhesives**;** Enbucrilate**;** Osteotomy**;** Polymerization; Bone Transplantation**;** Osseointegration

INTRODUCTION

In comminutive fractures of the diaphysis of long bones, the cortical bone fragments behave like autologous grafts and often require internal fixation[1]. This leads to a need for two surgical procedures: firstly, to reduce the factures and place implants such as plates, screws, steel wires, pins or intramedullary nails; secondly, to remove the implant[2].

Furthermore, some authors have reported a variety of complications from using metal implants, such as extrusion of the material, palpation through the skin, bone growth disorders, bone reabsorption, osteoporosis and interference with computed tomography and magnetic resonance imaging techniques[3].

The cost of metal implants is also an important factor to be considered. Their high price makes fracture treatment expensive, in addition to the longer duration of operations involving metal implants, with their consequent additional costs. Therefore, it would be desirable to have a fixation method that would stabilize bone fragments at a lower cost, without the complications inherent to using metal implants[4].

Cyanoacrylates are a group of fast-polymerization adhesives that started to be used in surgery in the 1960s[5]. These would make it possible to use this method, since they are absorbable, biocompatible, easy to use, cost-cost, sterilizable in ethylene oxide and radiotransparent, and have the property of adhering to wet surfaces[6].

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Since the potential use of cyanoacrylates for treating fractures has received little attention, it was decided to study the effect of butyl-2-cyanoacrylate in osteotomies and bone grafts, from the macroscopic and radiographic points of view.

METHODS

Forty-eight adult male New Zealand White rabbits (*Oryctolagus cuniculus*) were used, with body weights ranging from 2,500 to 4,000 g. They came from the vivarium of FACIMPA, and were housed in individual cages, with natural illumination and room temperature, and were fed with commercial feed that was appropriate for the species, *ad libitum*. The animals were allowed a two-week adaptation period. The experiment was conducted at the Experimental Surgery Laboratory of the Department of Clinical and Surgical Medicine of FACIMPA.

Four groups of 12 animals each were formed randomly. They were named A, B, C and D, according to the lengths of the observation periods after the surgical procedure, which were respectively two, four, eight and sixteen weeks.

The ethical recommendations of the Council for International Organizations of Medical Sciences (CIOMS) and the principles of the Brazilian College of Animal Experiments were followed. The study was approved by the Research Ethics Committee of the Federal University of São Paulo/Hospital São Paulo (Ref. CEP no. 436/00).

Pre-anesthesia was accomplished using 1% acepromazine, intramuscularly (IM) at a dose of 2mg/kg. Forty minutes later, the animals were anesthetized using ketamine hydrochloride at a dose of 40mg/kg and 2% xylazine hydrochloride at a dose of 8mg/kg, injected IM.

One ml of 1% lidocaine hydrochloride was infiltrated into the lateral dorsal region of the distal third of the forearms and then a straight incision of 3 cm in length was made in the skin. The common extensor tendons of the fingers were pushed away to one side and the radial extensor of the carpus to the other side, thereby exposing the distal half of the radius through extraperiosteal dissection. A fragment of the radius of 1 cm in length was removed as a bone graft, after two complete transverse osteotomies using a rotary saw with a steel disc, attached via an adaptor to a battery-operated drilling device (Dremel® model 750), with a velocity of 5,000 rotations per minute, under continual irrigation with 0.9% physiological serum. The distal osteotomy was performed 1.5 cm proximally to the radiocarpal joint. Following this, the fragment of the radius was replaced in this location as an autologous cortical graft, without removing the periosteum. A drop of blue-colored butyl-2-cyanoacrylate tissue adhesive (Histoacryl®, B. Braum, Melsungen AG, Germany) was placed on each osteotomy, in the direction from dorsal to ventral, by squeezing the original packaging, which was provided with a capillary tip (Figure 1).

In the other thoracic limb, the bone graft was simply replaced at the same location.

The epidermis was sutured using simple stitches of 4-0 monofilament nylon.

The side on which the tissue adhesive was used was alternated: thus, if the adhesive was used on the right thoracic limb in one animal of a given group, it would be used on the left limb in the next animal of the same group.

The animals were observed every day for the first week and then once a week until the date of sacrifice. If any animal presented signs of infection with a compromised general state or fracture, it was sacrificed and replaced, in order to avoid distress and to maintain the standardization of the sample.

At the predetermined times, the animals were anesthetized and the operative wounds were examined with regard to the presence of dehiscence, infection or fistula.

The animals were sacrificed by means of an intracardiac injection of 3 ml of 10% potassium chloride (KCl). The forearms were then removed, the soft

Figure 1 – Surgical procedure: after replacement of the bone graft, showing a drop of adhesive placed on the distal osteotomy, and already polymerized on the proximal osteotomy.

tissue was also removed and the surgical specimens were observed with regard to the presence of deformity and blue marks. The stability of the bone graft was tested by observing its movement upon manipulation using anatomical tweezers.

The surgical specimens from the same animal were labeled and radiographed in pairs, in anteroposterior (AP) and lateromedial (LM) positioning, at a standard distance of 100 cm.

Scoring systems were established for the displacement of the bone graft, union of the osteotomies and integration of the bone graft at the proximal and distal osteotomies, in the AP and LM radiographic views. The worse result prevailed for each item, i.e. if the displacement of the bone graft at the proximal osteotomy on the right side in AP view was 0 and it was 1 in LM view, the score of 0 prevailed. Presence or absence of fractures in the bone graft or in the ulna was also analyzed in the two radiographic views. The scoring was done in the increasing direction, from the worst result to the best result, for all the items.

Displacement of the bone graft: 0 – greater than 50% of the osteotomy surface; 1 – up to 50% of the osteotomy surface; 2 – aligned.

Union of the osteotomies: 0 – continuity solution on the osteotomy surface greater than 50%; 1 – continuity solution on the osteotomy surface up to 50%; 2 – absence of continuity solution on the osteotomy surface.

Integration of the bone graft: 0 – absence of integration; 1 – remodeling of the intramedullary canal; 2 – total remodeling of the cortical bone.

Fractures of the bone graft and ulna: 0 – present; 1 – absent.

The radiographs were evaluated by three independent observers at different times and without knowledge of the animal group (Figure 2).

STATISTICAL METHOD

To analyze the results, the following tests were performed: analysis of variance to study the homogeneity of the animals' weights before the surgery, between the four groups; t test to compare the animals' weights at the beginning and end of each group; Friedman's analysis of variance to compare the values of the variables measured by the three observers who participated in the experiment (this analysis was applied separately for the results observed among the limbs with adhesive and among the control limbs);

Figure 2 – Radiograph showing bone grafts (BG) misaligned by up to 50% on the surface of the proximal osteotomy (PO) and distal osteotomy (DO) on the right side (R) and aligned in the DO on the left side (L); continuity solution greater than 50% on the surfaces of the PO and DO on the R and L sides; absence of integration of the BG; and absence of fractures (rabbit no. 27, group A; R = control and L = adhesive).

and Wilcoxon's test with the aim of comparing the results observed with and without the adhesive for each rabbit.

The rejection level for the nullity hypothesis was set at 0.05 or 5% ($\alpha \leq 0.05$), and significant values were indicated using boldface type.

RESULTS

The animals' weights compared between the four groups before the operation were shown to be homogenous.

There was no significant difference in weight from before the operation to the time of sacrifice between the groups, or in the $\Delta\%$ of the animals' weights between the groups.

There was no significant difference between the side with the adhesive and the control side, with regard to dehiscence, infection, fistula, deformity of the surgical specimen or stability of the bone graft.

The presence of blue marks remaining from the adhesive was observed in all the surgical specimens in which the adhesive had been used, and these marks were absent from all the controls.

Since there was no statistically significant difference between the three observers in the analyses on the radiographs, in relation to union of the osteotomies, displacement and bone graft integration, it was decided to use the scores from observer 3, since these were the scores that came closest to the best result expected.

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In group A, in the proximal osteotomies with adhesive, there was less deviation of the bone graft. In the other groups, there was no significant difference between the adhesive and control limbs.

In group C, the bone union was better in the proximal osteotomies with adhesive. In the other groups, it was observed that the scoring relating to bone union increased with time, but without any statistically significant difference between the adhesive and control limbs.

In group C, the bone graft integration was better in the proximal osteotomies with adhesive. In groups A and B, no bone graft integration occurred in most of the osteotomies.

Consolidation and integration of the bone graft in the adhesive and control limbs occurred in most of the osteotomies before the 16th week of observation.

No fractures of the bone graft occurred in any of the animals.

There was no significant difference between the side with adhesive and the control side in relation to ulnar fractures (Tables 1, 2, 3, 4 and 5).

DISCUSSION

Through the osteotomies, it was sought to simulate comminutive fractures with defined comminution pattern and soft-tissue injury, and with established osteotomy sites and distance between them. Complete displacement of the bone segment was accomplished: the segment was removed and then replaced in the original site. The bone fragment thus formed an autologous cortical bone graft and the osteotomies could be considered to be fractures. The osteotomies were performed in the region of the cortical bone and the site was irrigated with physiological serum in order to avoid heating and bone necrosis[7,8]. A previous study using bone tissue from a cadaver showed that the rigidity of butyl-2-cyanoacrylate adhesive is five times greater on cortical bone than on spongy bone and that it exceeds the minimum value for use as a bone adhesive[9].

The periosteum was maintained on the bone graft and at the ends of the bone because it was found in a previous study that if it was removed, replacement of the dead cells of the cortical bone in the graft and union of the osteotomies was much slower than in a group with periosteum[10]. In another experimental study, it was shown that the periosteum made a 30%

Table 1 – Proximal and distal osteotomies according to three observers' readings of displacement, radiographic union and integration of bone grafts with adhesive and without adhesive (control), in group A (2 weeks).

Proximal with adhesive		Obs. 1	Obs. 2	Obs. 3	Friedman's analysis of variance
Displacement	x^-	1.42	1.33	1.25	x^2=2.00 (p=0.368) NS
	Mi	1	1	1	
Radiographic union	x^-	0	0	0	No need for analysis
	Mi	0	0	0	
Integration	x^-	0	0	0	
	Mi	0	0	0	
Proximal control					
Displacement	x^-	0.83	0.92	0.67	x^2=3.50 (p= 0.174) NS
	Mi	1	1	1	
Radiographic union	x^-	0	0	0	No need for analysis
	Mi	0	0	0	
Integration	x^-	0	0	0	
	Mi	0	0	0	
Distal with adhesive					
Displacement	x^-	1.83	1.75	1.83	x^2=2.00 (p=0.368) NS
	Mi	2	2	2	
Radiographic union	x^-	0	0.08	0.33	x^2=5.60 (p=0.06) NS
	Mi	0	0	0	
Integration	x^-	0	0	0	x^2=3.71 (p=0.156) NS
	Mi	0	0	0	
Distal control					
Displacement	x^-	1.5	1.5	1.5	x^2=0.00 (p=1.00) NS
	Mi	1.5	1.5	1.5	
Radiographic union	x^-	0	0	0	No need for analysis
	Mi	0	0	0	
Integration	x^-	0	0	0.08	x^2=2.00 (p=0.368) NS
	Mi	0	0	0	

Legend: x-: mean - Mi: median - NS: not significant
Sources: DOT. UNIFESP-EPM UNIVÁS-FACIMPA.

contribution towards formation of new bone in the bone graft[11].

The control in the present study was in the same animal, because the normal variation in biological activity (reabsorption, apposition, porosity and new bone formation) in the same segment of the skeleton in different animals is so large that using different animals as controls presents limitations. It is very important to compare experimental and control bone grafts in the same animal, because if one evolves poorly, the other will also evolve in this manner[12]. It was decided to vary the side on which the operative technique under examination (i.e. osteotomy with adhesive) was used in order to avoid biased sampling.

The bone graft was replaced in the original location, thus maintaining well adapted proximal and distal surfaces. Two factors are important in obtaining union between the bone ends and the bone graft: perfect

Table 2 - Proximal and distal osteotomies according to three observers' readings of displacement, radiographic union and integration of bone grafts with adhesive and without adhesive (control), in group B (4 weeks).

Proximal with adhesive		Obs. 1	Obs. 2	Obs. 3	Friedman's analysis of variance
Displacement	x^-	1.33	1.42	1.42	x^2=0.67 (p=0.717) NS
	Mi	1	1	1	
Radiographic union	x^-	0	0	0	No need for analysis
	Mi	0	0	0	
Integration	x^-	0	0	0	
		0	0	0	
Proximal control					
Displacement	x^-	1.42	1.5	1.58	x^2=1.20 (p=0.549) NS
	Mi	1	2	2	
Radiographic union	x^-	0	0	0	No need for analysis
	Mi	0	0	0	
Integration	x^-	0	0	0.08	x^2=2.00 (p=0.368) NS
		0	0	0	
Distal with adhesive					
Displacement	x^-	1.75	1.92	1.92	x^2=2.00 (p=0.368) NS
	Mi	2	2	2	
Radiographic union	x^-	0.17	0.25	0.33	x^2=2.00 (p=0.368) NS
	Mi	0	0	0	
Integration	x^-	0	0.25	0.25	x^2=3.80 (p=0.150) NS
		0	0	0	
Distal control					
Displacement	x^-	1.58	1.67	1.75	x^2=2.00 (p=0.368) NS
	Mi	2	2	2	
Radiographic union	x^-	0.25	0.33	0.67	x^2=7.538 Obs. 3 > 1 e 2 (p=0.023)
	Mi	0	0	0	
Integration	x^-	0	0.33	0.33	x^2=5.69 (p=0.058) NS
		0	0	0	

Legend: x-: mean - Mi: median - NS: not significant
Sources: DOT. UNIFESP-EPM UNIVÁS-FACIMPA.

Table 3 - Proximal and distal osteotomies according to three observers' readings of displacement, radiographic union and integration of bone grafts with adhesive and without adhesive (control), in group C (8 weeks).

Proximal with adhesive		Obs. 1	Obs. 2	Obs. 3	Friedman's analysis of variance
Displacement	x^-	1.42	1.5	1.5	x^2=0.50 (p=0.779) NS
	Mi	2	2	2	
Radiographic union	x^-	0.33	1	1.33	x^2=12.60 Obs. 3 > 1 e 2 (p=0.002)
	Mi	0	1	2	
Integration	x^-	0.33	1	0.92	x^2=8.96 Obs. 3 > 1 e 2 (p=0.011)
		0	1	1	
Proximal control					
Displacement	x^-	1.17	1.25	1.17	x^2=0.67 (p=0.717) NS
	Mi	1	1	1	
Radiographic union	x^-	0.08	0.67	0.58	x^2=8.32 Obs. 2 e 3 > 1 (p=0.016)
	Mi	0	0.5	0	
Integration	x^-	0.5	0.67	0.5	x^2=1.60 (p=0.449) NS
		1	1	0.5	
Distal with adhesive					
Displacement	x^-	1.83	1.92	1.92	x^2=2.00 (p=0.368) NS
	Mi	2	2	2	
Radiographic union	x^-	0.75	1.08	1.42	x^2=7.28 Obs. 3 > 1 e 2 (p=0.026)
	Mi	0.5	1	2	
Integration	x^-	0.75	1.25	1.58	x^2=11.56 Obs. 3 > 1 e 2 (p=0.003)
		1	1	2	
Distal control					
Displacement	x^-	1.75	1.83	1.67	x^2=3.00 (p=0.223) NS
	Mi	2	2	2	
Radiographic union	x^-	0.5	1.17	1.25	x^2=11.84 Obs. 3 > 1 e 2 (p=0.003)
	Mi	0	1	2	
Integration	x^-	0.58	1.17	1.42	x^2=10.30 Obs. 3 > 1 e 2 (p=0.006)
		0	1	2	

Legend: x-: mean - Mi: median - NS: not significant
Sources: DOT. UNIFESP-EPM UNIVÁS-FACIMPA.

adaptation and immobilization. When the placement of the graft is perfect, muscle action produces considerable tension that forces one bone structure against the other, thus functioning as a powerful stimulus for osteogenesis, both in the graft and in the bone ends. The quantity of bone callus that forms is small and the transformation into bone is faster[10,13].

The adhesive butyl-2-cyanoacrylate was chosen because it presents excellent adhesiveness, sterility and elasticity and low toxicity to tissues; does not induce cell neoplasia; has rapid polymerization; is easy to apply to organs of animals of different species; and is eliminated through the normal excretion routes, i.e. urine and feces, and probably also through the respiratory system[9,14-18]. Another important factor in choosing butyl-2-cyanoacrylate is that it has already been used in humans, in some European countries and in Canada, without reports of toxic effects[4,19].

As suggested by other authors, a drop of the adhesive was place on each osteotomy, in the direction from dorsal to ventral, so as to allow bone formation around the adhesive[20,21].

The operation made it impossible for the animals to walk until the seventh day after the operation. From then onwards, they started to slowly improve, supporting themselves on their operated limbs. Transmission of mechanical force through the osteotomies is important in order to minimize the effect of disuse, thereby positively influencing the rate, degree and efficacy of the repair and the remodeling of the bone graft. When bone grafts are placed in soft tissue without being subjected to stress, they tend to be reabsorbed[1,22,23]. In some animals, diffuse edema in the front paws was observed on the day after the operation, which ceased spontaneously after around 10 days, as also observed by other authors[8].

Ten animals were replaced: six because of fractures

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Table 4 - Proximal and distal osteotomies according to three observers' readings of displacement, radiographic union and integration of bone grafts with adhesive and without adhesive (control), in group D (16 weeks).

Proximal with adhesive		Obs. 1	Obs. 2	Obs. 3	Friedman's analysis of variance
Displacement	x^-	1.83	2	2	$x^2=4.00$ (p=0.135) NS
	Mi	2	2	2	
Radiographic union	x^-	0.25	1.67	1.75	$x^2=22.17$ Obs. 2 e 3 > 1 (p=0.000)
	Mi	0	2	2	
Integration	x^-	0.58	1.83	1.92	$x^2=17.43$ Obs. 2 e 3 > 1 (p=0.000)
		0	2	2	
Proximal control					
Displacement	x^-	1.92	2	1.92	$x^2=1.00$ (p=0.607) NS
	Mi	2	2	2	
Radiographic union	x^-	0.67	1.58	1.92	$x^2=17.11$ Obs. 3 > 1 e 2 (p=0.000)
	Mi	1	2	2	
Integration	x^-	1	1.67	1.92	$x^2=12.24$ Obs. 3 > 1 e 2 (p=0.002)
		1	2	2	
Distal with adhesive					
Displacement	x^-	1.92	2	2	$x^2=2.00$ (p=0.368) NS
	Mi	2	2	2	
Radiographic union	x^-	0.83	1.67	1.75	$x^2=13.79$ Obs. 3 > 1 e 2 (p=0.001)
	Mi	1	2	2	
Integration	x^-	1.08	1.75	1.92	$x^2=9.50$ Obs. 3 > 1 e 2 (p=0.009)
		1	2	2	
Distal control					
Displacement	x^-	2	2	2	No need for analysis
	Mi	2	2	2	
Radiographic union	x^-	1.58	1.83	1.92	$x^2=3.88$ (p=0.144) NS
	Mi	2	2	2	
Integration	x^-	1.58	1.83	2	$x^2=6.62$ Obs. 3 > 1 e 2 (p=0.037)
		2	2	2	

Legend: x-: mean - Mi: median - NS: not significant
Sources: DOT. UNIFESP-EPM UNIVÁS-FACIMPA.

Table 5 - Displacement, radiographic union and integration of bone grafts after 2, 4, 8 and 16 weeks (groups A, B, C and D), with adhesive and without adhesive (control), in the proximal and distal osteotomies, according to the mean scores. Wilcoxon's test (z and p).

Displacement of bone graft								
	Proximal osteotomy				Distal osteotomy			
	Adhesive	Control	zcalc.	p	Adhesive	Control	zcalc.	p
Group A	1.25	0.67	-2.33	0.02	1.83	1.5	-1.63	0.1
Group B	1.42	1.58	-0.81	0.41	1.92	1.75	-0.81	0.41
Group C	1.5	1.17	-1.41	0.15	1.92	1.67	-1.34	0.18
Group D	2	1.92	-1	0.31	2	2	0	1

Radiographic union of bone graft								
	Proximal osteotomy				Distal osteotomy			
	Adhesive	Control	zcalc.	p	Adhesive	Control	zcalc.	p
Group A	0.33	0.08	-1.34	0.18	0.33	0	-1.63	0.1
Group B	0	0	0	1	0.33	0.67	-1	0.31
Group C	1.33	0.58	-2.12	0.03	1.42	1.25	-0.55	0.57
Group D	1.75	1.92	-1.41	0.15	1.75	1.92	-1.41	0.15

Integration of bone graft								
	Proximal osteotomy				Distal osteotomy			
	Adhesive	Control	zcalc.	p	Adhesive	Control	zcalc.	p
Group A	0	0	0	1	0.62	0.29	-0.82	0.41
Group B	0	0.08	-1	0.31	0.25	0.33	-1	0.31
Group C	0.92	0.5	-2.24	0.02	1.58	1.42	-0.74	0.45
Group D	1.92	1.92	0	1	1.92	2	-1	0.31

Sources: DOT. UNIFESP-EPM UNIVÁS-FACIMPA.

(which occurred on the control side in five animals and on both sides in one animal); and four because of deep infection with compromising of their general state (two on the side with adhesive and two on the control side). Although the number of animals that suffered fractures was small, the fact that these occurred in greater number on the control side suggests that the radius with a bone graft and adhesive was able to bear greater weight, thus sparing the ulna from axial loads.

The anti-infection power of butyl-2-cyanoacrylate[17] was not confirmed, since no significant difference in relation to infection was found between the side with adhesive and the control.

On macroscopic examination, deformity of the surgical specimens was observed in the animals in groups A and B, without any significant difference between the side with adhesive and the control side. In the other two groups (C and D), no deformity was seen, probably because of bone remodeling that occurred during the consolidation of the osteotomies, as also observed by other authors[8].

After four weeks, the bone graft was stable upon manipulation, in all the surgical specimens, in the same way as observed by other authors[22]. Absence of movement upon manipulation is considered to be one of the clinical criteria for diagnosing union of the osteotomies[24]. The adhesive did not interfere with the clinical consolidation process of the osteotomies up to this observation time.

Polymerization of the adhesive occurred after around 30 seconds, and there was no change in adhesive color from blue to white, which was observed by some other authors[2,19,25].

Remains of adhesive were found in 100% of the animals. Thus, a longer observation period will be necessary in order to determine the time taken for the adhesive and its action on tissues to be eliminated. It has been recognized that esters with greater numbers of carbon atoms degrade slowly, and some authors have suggested that complete removal of the adhesive may never be attained[6,7,15,17,20,26].

It was observed in analyzing the radiographs that the adhesive was responsible for lower deviation of the bone graft in proximal osteotomies with adhesive, after two weeks of observation (p = 0.02; Table 5), as also seen by other authors, who found that the bone fragments were kept in position through using cyanoacrylate adhesive, even though the animals supported themselves early on, with the operated limb[3,25,27,28]. These results are also concordant with *in vitro* observations, which showed that butyl-2-cyanoacrylate presented high initial adhesive resistance[2,14].

It was observed that the radiographic union was best in the proximal osteotomies with adhesive in group C (p = 0.03; Table 5).

By the 16th week, it was found that most of the osteotomies presented union, without any significant difference between the adhesive and control groups. This was not in agreement with some other authors, who observed that all the osteotomies reached consolidation between three and eight weeks after the operation[22,29,30].

Radiographic integration of the bone graft with the bone ends occurs when then there is continuity of the cortex and medullary canal, absence of the osteotomy line and presence of a mineralized bone callus, i.e. structural and functional interlinking between an organized bone and the graft[25].

The integration of the bone graft was better in the proximal osteotomies with adhesive, in group C (p = 0.02; Table 5). Integration of most of the bone grafts also occurred by the 16th week of observation, without any statistically significant difference between the adhesive and control groups.

Integration of autologous cortical bone grafts of the diaphysis of the radius and ulna were observed on radiographs in other studies after six and sixteen weeks[22,31]. Although there is a close relationship between revascularization of the bone graft and its integration, it was shown that incorporation of the cortical bone graft was not expected, even when fixed in a stable manner to a healthy bed, with good vascularization. Even under these excellent conditions, the incorporation process was complex and controlled by multiple factors, such that it might continue for months[32].

The proximal osteotomies with adhesive showed less deviation of the bone graft after two weeks, and greater proportions of union and integration of bone grafts after eight weeks. This suggests that good adaptation and stability of the bone graft in the receptor bed were important for this result[13].

The adult age of these animals, along with the more rigorous radiographic criterion for considering results to poor in the two radiographic views, may have contributed towards slower attainment of bone union and bone graft integration than reported in the literature.

There were no occurrences of fractures in the bone graft in any of the animals. The probable cause of the ulnar fractures was mechanical overload due to the axial forces that the ulna had to bear, without any significant difference between the adhesive and control sides. The ulna mainly bears transverse shearing forces, while the radius bears axial loads[8].

The radiographic analysis on the bone callus of each of the osteotomies was impaired because of formation of a single bone callus. However, this did not impair the analysis on the union of the osteotomies since it was concluded based on analysis of tibial fractures in adult rabbits[33] that the orthopedist and radiologist did not have a secure basis for radiographically diagnosing fracture consolidation. The radiographic size of the bone callus is a poor prognostic factor in relation to the resistance of the fracture union. Reestablishment of resistance and rigidity after a fracture is more related to the quantity of new bone joining the bone fragments than to the quantity of bone callus[23].

CONCLUSIONS

The adhesive was not completely metabolized, 16 weeks after the operation.

Clinical consolidation of the osteotomies was achieved in four weeks.

The adhesive stabilized the bone graft over the first two weeks.

The adhesive did not interfere with consolidation of the osteotomies, or with integration of the bone grafts, after 16 weeks of radiographic observation.

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