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The use of N-butyl-2-cyanoacrylate (Histoacryl) in primary tendon repair: a biomechanical study with sheep flexor tendons

Tendon onarımında N-butil-2-siyanoakrilat (Histoakril) kullanımı: Koyun fleksör tendonuyla biyomekanik çalışma

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Amaç: Bu çalışmada, tendon periferik onarımında devamlı epitendinöz dikiş ve biyoçözünür bir yapıştırıcı olan N-butil-2-siyanoakrilat (Histoakril) (NBSA) kullanılarak yapılan onarımların biyomekanik özellikleri karşılaştırıldı.

Çalışma planı: Çalışmada 24 adet koyun fleksör tendonu kullanıldı. Orta seviyeden kesim işleminden sonra 12 tendona (grup 1) no 2 prolen ile modifiye Kessler kor dikiş ve 3/0 prolen ile devamlı epitendinöz dikiş yapıldı. Diğer 12 tendonda ise (grup 2), modifiye Kessler kor dikişten önce kesi hattına NBSA sürüldü. Her iki gruptan altışar tendona hidrolik test cihazında yüklenme-deformasyon (20 mm/dak hızda gerilme) ve siklik yüklenme-deformasyon (1-15 N arası 20 siklus/dakika frekansta yüklenme) testleri uygulandı. İki testte de onarım sahasında 1 mm boşluk oluşumu onarımın bozulması olarak yorumlandı.

Sonuçlar: Grup 1'de onarımın bozulması için gerekli yük ortalama 27.3 N (dağılım 25-32 N), ikinci grupta ise 50.4 N (dağılım 32-63 N) bulundu (p=0.022). Grup 1'de onarımın bozulmasına kadar yapılan siklus sayısı ortalama 140 (dağılım 45-250), grup 2 de ise 350 (dağılım 150-600) idi (p=0.032).

Çıkarımlar: Bu çalışmada, tendonlarda NBSA ile yapılan periferik onarımın, devamlı epitendinöz dikiş ile yapılan onarıma göre biyomekanik açıdan daha avantajlı olduğu görüldü.

Anahtar sözcükler: Biyomekanik; siyanoakrilat/terapötik kullanım; el yaralanması/cerrahi; materyal testi/yöntem; koyun; dikiş teknikleri; tendon yaralanması/cerrahi; gerilme kuvveti.

Objectives: In this study, the biomechanical properties of peripheral tendon repair with the use of epitendinous suture technique and N-butyl-2-cyanoacrylate (Histoacryl) (NBSA), a biodegradable glue, were compared.

Methods: Twenty-four flexor tendons were harvested from sheep hind limbs. Following transection of the tendons, 12 tendons (group 1) were repaired with modified Kessler core sutures using no 2 prolene and epitendinous running sutures with 3/0 prolene. In the other 12 tendons (group 2), NBSA was applied between the cut surfaces before placing modified Kessler core sutures. Placed on an hydrolic test machine, half of the tendons from each group were subjected to load to failure with a tensile force of 20 mm/min and the other half to cyclic loading with a tensile loading between 1-15 N at a rate of 20 cycles/min. Observation of a gap of 1 mm between the tendon ends in each test was regarded as repair failure.

Results: The mean load to failure was 27.3 N (range 25 to 32 N) for group 1 and 50.4 N (range 32 to 63 N) for group 2 (p=0.022). The mean number of cycles at failure was 140 (range 45 to 250) in group 1 and 350 (range 150 to 600) in group 2 (p=0.032).

Conclusion: Our results showed that peripheral tendon repair with the use of NBSA has biomechanical advantages over repair with the epitendinous running suture technique.

Key words: Biomechanics; cyanoacrylates/therapeutic use; hand injuries/surgery; materials testing/methods; sheep; suture techniques; tendon injuries/surgery; tensile strength.

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Controlled active motion protocols yield superior results when compared to early passive motion protocols during the rehabilitation period of hand flexor tendon injuries.[1-3] Active rehabilitation programs increase the speed of tendon healing and remodeling; preventing adhesion and deformity at the repair zone.[2,4-6] This condition requires a strong tendon repair that can permit early active motion. The strength of tendon repair depends not only on core suture but as well on peripheral repair technique. [7-9] Contemporarily, the most frequently employed peripheral repair technique is epitendinous running suturing. However, experimental studies showed that this suture technique is biomechanically inferior to cross-stitch and Halsted technique.[9-12] In cross-stitch and Halsted technique the surgical technique is complex and over manipulation of transected ends of tendons and increased surface area of suture material causing friction with peripheral tissue lead to adhesion.[11,13] A tendon repair technique that can be easily employed in surgical practice and also biomechanically of sufficient strength shall provide early active motion at the same time preventing peripheral adhesion of tendons.

N-butyl-2-cyanoacrylate (NBSA) is bacteriostatic, bioresorbable, hemostatic adhesive with a long half life and good tissue compatibility.[14-16] Trail et al. [17] compared continuous epitendinous suturing with peripheral repair performed with NBSA and observed that the latter was superior. However, in their study only loading-deformation experiments were done; cyclic loading-deformation was not observed. Loading on the repair site during the rehabilitation of tendon repair is mostly cyclic.[12,18] Thus when a new repair technique is researched its complete biomechanical properties should be tested. In our study, biomechanical properties of epitendinous running sutures and peripheral repair done with NBSA were compared.

Materials and methods

Twenty-four flexor tendons harvested from sheep hind limbs were used in this study. Biomechanical experiments were performed employing Testometric micro 350 hydrolic test machine (Lancashire, UK) and load-deformation curve obtained from a system linked computer. In biomechanical studies done using tendons, the ends are attached to the test machine with special clamps aiming to prevent release of tendons when tension force is applied. In our study the suitability of the clamps of Testometric micro 350 hydrolic test machine was assessed initially. This was achieved by placing a tendon of 25cm length to the test machine and applying a tension of 20mm/min. The both ends of the tendon were marked and checked for any release from the clamps. Load-deformation curve was controlled by the computer attached to the machine. When loading was 1450 N load to failure and a deflection in load-deformation curve were observed. This value was considered to be high enough enabling firm attachment of the tendon to the system.

Twenty-four (25x1 cm) tendons were harvested from sheep in half an hour following their death and kept in deep freezer. On the day of experiment they were taken out from deep freezer and thawed in room temperature. Following transection of tendons, 12 tendons (Group 1) were repaired with modified Kessler core sutures using no 2 prolene and epitendinous running sutures with 3/0 prolene. In the other 12 tendons (Group 2), NBSA was applied between the cut surfaces before tying modified Kessler core sutures. During core suturing, ends of tendons are compressed for two minutes. Tendons are kept in serum physiologic during the experiment.

Load to failure experiment

Six tendons from each group were placed on a hydrolic test machine. Distance between the clamps holding the tendon ends were calibrated as 10cm. Pretension of 1N was performed for two minutes, and then a tension force of 20mm/min was applied. Load to failure curve was recorded from the computer attached to the system. Observation of a gap of 1mm between the tendon ends was considered as a repair failure, and a sudden change in the curve was observed and noted.

Cyclic loading to failure experiment

Six tendons from each group were placed on a hydrolic test machine. Pretension of 1N was applied for two minutes after when a cyclic loading of 1-15N at a rate of 20cycles/min was applied. Before the initiation of the experiment 1000 cycles were aimed. A gap formation of 1mm in the relaxation phase was considered as a repair failure. Number of cycles when the gap was formed was recorded. The results of both experiments were compared using Student-t test.

Results

Repair failure was noted as release of epitendinous suture from the tendons in epitendinous suturing, and as seperation of adhesive material in the NBSA used group. The mean load to failure was 27.3 N (range 25-32N) for the group in which core and epitendinous running sutures were used; while it was 50.4 N (range32-63 N) for the group in which core suturing and NBSA application were performed (Figure 1a). The difference was significant (p=0.022).

The mean number of cycles at failure was 140 (range 45-250) in group 1 and 350 (range 150-600) in group 2 (Figure 1b). The difference regarding the number of cycles was significant (p=0.032).

Discussion

Recently numerous studies have been done researching the tendon structure, and its biomechanics, response to trauma and repair techniques. These studies have led to the conclusion that earlier the active motion, faster the rate of tendon healing, and lower the peritendinous tissue adhesion.[2,5,19-21] Commencing early active motion requires a strong repair. The strength of tendon repair not only depends on the core suture technique, but as well on the peripheral repair technique.[7-10] In our study, two types of peripheral repair techniques with a concomitant core suture technique were compared. It was concluded that modified Kessler technique augmented with NBSA yielded superior results when compared to modified Kessler and epitendinous running suture techniques.

The strength of a tendon repair depends on the technique and suture material.[12] Two forms of damage are evident when the strength of repair technique is tested biomechanically. First is the slippage of the suture material from the tendon ends; second is the rupture of a suture material.[7,12] In our study we tried to use thick material (core suture with no2 prolene, epitendinous suture with 3/0 prolene) in order to prevent failure due to rupture of suture material. Differing from the literature, we surmised that our approach enabled us to assess the biomechanical variability of different peripheral repair techniques independent of suture materials.

Today the most commonly used technique in peripheral tendon repair is running epitendinous suturing. It is known that this technique renders an additional strength of 700 grams to the repair.[5] This strength varies with the distance between the suture and transected end of a tendon as well as the depth of the suture.[8] However in practice determining the tightness of the epitendinous suture, its location and depth may not always be possible. Although other suture techniques as cross-stitch and Halsted renders a biomechanically stronger repair,[9-12] they incur problems as complexity, frequent manipulation of transected tendon ends and finally increased adhesion to the surrounding tissue resulting from friction between the tissue and the suture material.[11,13] It is also evident that each suture placed in the tendon disrupts its vascularity.[22] We believe that peripheral repair with NBSA used in our study is a method that can be easily applied in a standart fashion.

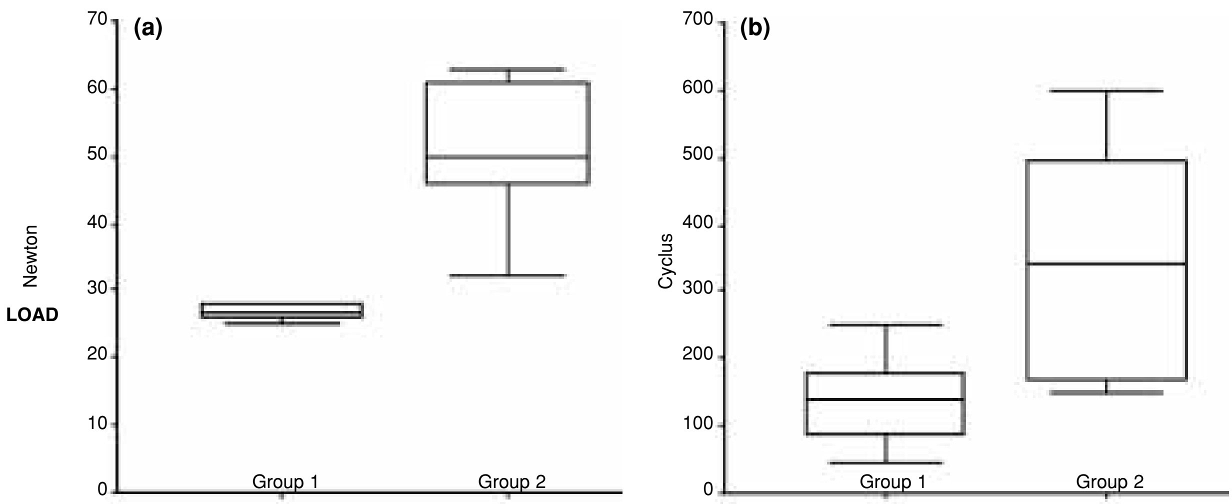

Figure 1a. Results of load to failure test in Group 1 and 2. **Figure 1b.** Results of cyclic loading to failure test in Group 1 and 2.

N-butyl-2-cyanoacrylate is a bacteriostatic, biodegradable, hemoastatic biological glue that has a long half life and biocompatibility.[14,16] Cyanoacrylate glue was first discovered by Ardis in 1949 and used surgically by Coover for the first time in 1959. [15] N-butyl-2-cyanoacrylate that was later developed was utilised as a strong tissue adhesive due to its being non histotoxic and availability as a glue even in non dry environment.[23] Today NBSA is used widely as a hemoastatic and embolic agent in obliteration of the fallopian tubes, retinal tears, corneal ulcus and placement of grafts.[15] Its use in fracture and osteotomy fixation is experimental and usally confined to the craniofacial and mandibular bones.[24,25] Shermak et al [15] reported that the glue disintegrated in the third week in most of the experimental subjects. Cyanoacrylate also has bacteriostatic and bacteriocidal effects.[23,24] However, Evans et al [26] showed that cyanoacrylate could be cytotoxic in their tendon cell culture experiments.

In the literature there are studies in which NBSA is used in tendon repairs. Trail et al [17] compared the biomechanical properties of NBSA and epitendinous suture and found that the former provided a 30-40% increase in repair site strength. However in this study only load to deformation was investigated, and cyclic load to deformation was omitted. Bonutti et al [14] compared techniques of Kessler and epitendinous sutures plus cyanoacrylate augmentation with Kessler and epitendinous sutures in rabbit Achilles tendons, and found that the former was superior biomechanically. However in this study, direct comparison between cyanoacrylate and epitendinous sutures was not done. In our study the repair techniques were compared using load to deformation and cyclic load to deformation experiments. In both experiments NBSA provided a stronger repair.

There are a few drawbacks of our study. In load to failure experiments the fact that the tendon ends were not attached to the test machine with special clamps might decrease reliability. In the pre experiment done to assess the reliability of our experiment the suitability of the clamps on the test machine for the tendon experiment was researched and an intact tendon of 25cm long was placed on the test machine and a tension of 20mm/min was applied. We observed that the minimum force required for the tendons to slippage from the clamps was 1450 N. We believe that our experiment is reliable as the maximum tension force used has been 63 N. Another drawback of our study was that the gap formed between the tendon ends was observed naked eye instead of using camera or digital system. Although in the literature this limit was 2mm [3,8], in order to decrease interpration errors this value was decreased to 1mm. This situation made it difficult for us to compare force (N) values in the literarture with ours.

Our findings showed us that NBSA repair technique in peripheral tendon repairs is biomechanically superior compared with running epitendinous suturing. However, in vivo studies are required to test its biocompatibity before utilising NBSA clinically.

References

1. Elliot D, Moiemen NS, Flemming AF, Harris SB, Foster AJ. The rupture rate of acute flexor tendon repairs mobilized by the controlled active motion regimen. J Hand Surg [Br] 1994;19:607-12.
2. Cullen KW, Tolhurst P, Lang D, Page RE. Flexor tendon repair in zone 2 followed by controlled active mobilisation. J Hand Surg [Br] 1989;14:392-5.
3. Silfverskiold KL, May EJ. Flexor tendon repair in zone II with a new suture technique and an early mobilization program combining passive and active flexion. J Hand Surg [Am] 1994; 19:53-60.
4. Lee H. Double loop locking suture: a technique of tendon repair for early active mobilization. Part II: Clinical experience. J Hand Surg [Am] 1990;15:953-8.
5. Strickland JW. Flexor tendons. Acute injuries. In: Green DP, Hotchkiss RN, Pederson WC, editors. Green's operative hand surgery. Vol. 2, 4th ed. New York: Churchill Livingstone; 1999. p. 1851-97.
6. Kubota H, Manske PR, Aoki M, Pruitt DL, Larson BJ. Effect of motion and tension on injured flexor tendons in chickens. J Hand Surg [Am] 1996;21:456-63.
7. Dona E, Gianoutsos MP, Walsh WR. Optimizing biomechanical performance of the 4-strand cruciate flexor tendon repair. J Hand Surg [Am] 2004;29:571-80.
8. Merrell GA, Wolfe SW, Kacena WJ, Gao Y, Cholewicki J, Kacena MA. The effect of increased peripheral suture purchase on the strength of flexor tendon repairs. J Hand Surg [Am] 2003;28:464-8.
9. Tang JB, Wang B, Chen F, Pan CZ, Xie RG. Biomechanical evaluation of flexor tendon repair techniques. Clin Orthop Relat Res 2001;(386):252-9.
10. Dona E, Turner AW, Gianoutsos MP, Walsh WR. Biomechanical properties of four circumferential flexor tendon suture techniques. J Hand Surg [Am] 2003;28:824-31.
11. Tran HN, Cannon DL, Lieber RL, Abrams RA. In vitro cyclic tensile testing of combined peripheral and core flexor tenorrhaphy suture techniques. J Hand Surg [Am] 2002;27: 518-24.

12. Mishra V, Kuiper JH, Kelly CP. Influence of core suture material and peripheral repair technique on the strength of Kessler flexor tendon repair. J Hand Surg [Br] 2003;28:357-62.
13. Wang B, Tang JB. Embedded cross-stitch suture: an alternative to current cross-stitch peripheral suture. J Hand Surg [Br] 2003;28:471-4.
14. Bonutti PM, Weiker GG, Andrish JT. Isobutyl cyanoacrylate as a soft tissue adhesive. An in vitro study in the rabbit Achilles tendon. Clin Orthop Relat Res 1988;(229):241-8.
15. Shermak MA, Wong L, Inoue N, Chao EY, Manson PN. Butyl-2-cyanoacrylate fixation of mandibular osteotomies. Plast Reconstr Surg 1998;102:319-24.
16. Vihtonen K, Vainionpaa S, Mero M, Patiala H, Rokkanen P, Kilpikari J, Tormala P. Fixation of experimental osteotomies of the distal femur in rabbits with bone cement and cyanoacrylate. Arch Orthop Trauma Surg 1986;105:133-6.
17. Trail IA, Powell ES, Noble J, Crank S. The role of an adhesive (Histoacryl) in tendon repair. J Hand Surg [Br] 1992; 17:544-9.
18. Pruitt DL, Manske PR, Fink B. Cyclic stress analysis of flexor tendon repair. J Hand Surg [Am] 1991;16:701-7.
19. Gelberman RH, Amifl D, Gonsalves M, Woo S, Akeson WH. The influence of protected passive mobilization on the healing of flexor tendons: a biochemical and microangiographic study. Hand 1981;13:120-8.
20. Gelberman RH, Botte MJ, Spiegelman JJ, Akeson WH. The excursion and deformation of repaired flexor tendons treated with protected early motion. J Hand Surg [Am] 1986; 11:106-10.
21. Gelberman RH, Nunley JA 2nd, Osterman AL, Breen TF, Dimick MP, Woo SL. Influences of the protected passive mobilization interval on flexor tendon healing. A prospective randomized clinical study. Clin Orthop Relat Res 1991;(264):189-96.
22. De Klerk AJ, Jonck LM. Tendon response to trauma and its possible clinical application. An experimental study in primates. S Afr Med J 1991;80:444-9.
23. Amarante MT, Constantinescu MA, O'Connor D, Yaremchuk MJ. Cyanoacrylate fixation of the craniofacial skeleton: an experimental study. Plast Reconstr Surg 1995; 95:639-46.
24. Ahn DK, Sims CD, Randolph MA, O'Connor D, Butler PE, Amarante MT, Yaremchuk MJ. Craniofacial skeletal fixation using biodegradable plates and cyanoacrylate glue. Plast Reconstr Surg 1997;99:1508-15.
25. Gosain AK, Song L, Corrao MA, Pintar FA. Biomechanical evaluation of titanium, biodegradable plate and screw, and cyanoacrylate glue fixation systems in craniofacial surgery. Plast Reconstr Surg 1998;101:582-91.
26. Evans CE, Lees GC, Trail IA. Cytotoxicity of cyanoacrylate adhesives to cultured tendon cells. J Hand Surg [Br] 1999;24:658-61.