REVIEW

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Flexor Tendon Repair with Fast-Absorbable Sutures: A Rupture Incidence-Focused Analysis of a Case Series and a Review

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SUMMARY
Hand flexor tendon repair with absorbable sutures has the advantage of leaving no foreign material within the tendon. However, clinical application of degradable materials in flexor tendon repair is limited to slow-absorbable PDS or Maxon sutures and commonly does not involve fast-absorbable sutures, probably, because of fear of ruptures. Meanwhile, a small number of reports have shown that in terms of tenorrhaphy failure fast-absorbable sutures are safe. It is also known that classical tendon repairs with a pull-out wire withstand intensive mobilization after wire removal. Furthermore, experimental research implies that fast-absorbable polyglycolic acid fibers seeded with tenocytes can strengthen tendon repair. The current article retrospectively analyses a series of 12 patients with predominantly complex hand injuries, in which 17 flexor digitorum profundus and four flexor pollicis longus tendon repairs with Vicryl (polyglactin 910, copolymer of polyglycolic and polylactic acid) were performed. Early postoperative passive mobilization was employed. The postoperative results were analyzed with particular reference to tenorrhaphy failure. Ruptures occurred in only two repairs. This was statistically insignificant when compared with a hypothetical set of cases consisting of only good and excellent outcomes. These results imply that hand flexor tendon repair with fast-absorbable sutures is rupture-safe if moderate postoperative mobilization is employed. However, as the calculated postoperative dynamics of the tenorrhaphy strength predicts failure of all fast-absorbable suture repairs during active motion at six weeks, more research is needed to clarify why this was not the case in the presented and other published series of patients.

KEY WORDS
Absorbable suture; flexor tendon; hand; repair; review.

INTRODUCTION

Use of absorbable sutures in hand flexor tendon repair could not be better motivated than it was done by Boyes who, not long before the era of synthetic absorbable materials, analogized pull-out wire removal with disintegration of a hypothetical suture at three weeks after tendon repair (1). Boyes' vision began to realize itself in the early 1970s with the emergence of the first synthetic absorbable suture composed of polyglycolic acid (PGA) (2-4).

Currently, both non-absorbable and slow absorbable (PDS and Maxon) sutures are used for flexor tenorrhaphies with varying prevalence (5-7). Traditionally, absorbable sutures have not been the surgeons' first choice in tendon surgery, probably because of fear of progressive loss of suture strength that can endanger the repair during postoperative mobilization. This tendency, however, seems to have been changing in favor of slow-absorbable threads (5, 8). The available clinical reports indicate that flexor tendon repair with slow-absorbable PDS (polydioxanone (9, 10)) followed by both passive (11) and active (7, 12, 13) postoperative mobilization would not produce a significant increase in rupture rate. Similar results can be achieved with Maxon (copolymer of glycolic acid and trimethylene carbonate (7, 9, 10)), which has an intermediate rate of biodegradation but is close to PDS in retaining tensile strength (14).

Experimentally, suitability of absorbable materials for flexor tendon repair has been explored by a number of researchers (14-22). However, tenorrhaphy with fast-absorbable sutures has been little studied. The three available experimental reports on tensile strength of tendons sutured with fast-absorbable PGA-based threads present contradictory results. Minta (23) did not observe any difference in mechanical performance between silk and PGA (Dexon (9, 10)) in Achilles tenorrhaphies of rabbits at 1, 2, 3, and 6 weeks. In an unpublished study, Ketchum (24) detected that, at 4 weeks, tendons sutured with PGA were weaker by half than tendons joined with polyester. Greulich *et al*. (25) used 4-0 and 5-0 Vicryl (polyglactin 910, copolymer formed from nine parts of PGA and one part of polylactic acid (9, 10, 26, 27)) sutures that were employed for Tsuge repair of rabbit tendons. This study focused on a tenorrhaphy technique, rather than on suture performance. The article reported average repair gapping of 2-3 mm after 6 weeks of immobilization and did not mention any ruptures. The authors further described their clinical application of looped Vicryl suture in about 60 cases of Tsuge repairs of hand flexor and extensor tendons. Unfortunately, no statistical details were given concerning several repair failures that were encountered. The only other available report on clinical use of Vicryl in hand tendon surgery involved extensor tenorrhaphies; no ruptures were observed (28). Vicryl has also been clinically used for Achilles tendon repairs (29-32); only few re-ruptures have been reported (29).
Vicryl is one of the few available braided absorbable sutures. Breakdown of polyglactin 910 occurs in aqueous environment by hydrolysis and does not require enzymes (33), as is the case with all synthetic absorbable materials (9). Coated Vicryl sutures lose their strength in a linear fashion (34-36). They retain about 50% of their original strength at approximately three weeks and only about 5% at five weeks after incubation in rat soft tissue (36). Similarly to all multifilament sutures, Vicryl has a high elastic modulus and is resistant to elongation (37-39). Notably, initial load to failure of Vicryl has been found to be higher than that of other absorbable sutures and of non-absorbable Ethibond (35) that is recommended for flexor tendon repair (14, 40).
While, differently from Vicryl, PDS and Maxon retain their initial strength at three weeks after incubation in a Ringer-type solution (35), these sutures have a disadvantage of being monofilaments, which may be associated with their lesser anchoring capacity as compared with braided sutures (39, 41-43). Vicryl is soft and fits well in with the tissue; braided texture prevents sliding of the suture loops through tissue (25). Vicryl has a high knot security (44), probably due to relatively high friction between threads (45), which may be more important than contribution of this property to increase in tendon gliding resistance (46, 47).

The below report retrospectively analyses clinical results of flexor tendon repair with Vicryl sutures with a particular reference to postoperative rupture incidence in a limited series of patients.

MATERIALS AND METHODS

From 1999 to 2001, Vicryl sutures were used by the author to repair 122 flexor and 45 extensor tendons in 51 patients with predominantly complex hand injuries. Bioethics committees and relevant institutional regulations did not exist at the time in the country where the current study was performed. The author certifies that all other applicable institutional and governmental regulations concerning the ethical use of human subjects were followed during the course of this study.
All cases of digital flexor tenorrhaphy ruptures and flexor repairs with a minimum follow-up of 10 weeks were included in the analysis. In regard to the possibility of progressive repair deterioration, this follow-up period was considered as sufficient, because ruptures mostly occur within the first five weeks (48), and the achieved range of active motion rarely decreases with time (49). Cases with articular fractures, multiple level amputations, and amputations in zones 1, 2, T1, and T2 were excluded. These injuries usually lead to joint stiffness and compromise functional recovery because of injury to delicate extensor mechanism.
Seventeen flexor digitorum profundus (FDP) and four flexor pollicis longus (FPL) tenorrhaphies in 12 patients were available for evaluation. A summary of the cases is presented in **table I**. Fifteen lacerations of the FDP tendons were associated with complete transection of the flexor digitorum superficialis (FDS) tendon, seven of which were repaired (cases 1, 5, and 8). Six flexor tenorrhaphies were accompanied by corresponding extensor tendon repairs (cases 1, 2, and 3).
Depending on the tendon diameter, tenorrhaphy involved a two-strand Kirchmayr-Kessler-type suture with 4-0, 3-0 or 2-0 Vicryl and a circumferential running suture with the same or a separate absorbable thread. A 5-0 and 6-0 Monocryl (a fast-absorbable monofilament (9)) was used as a peripheral suture in cases 9 and 10, respectively. The extensor tendons were also sutured with Vicryl.
The patients were taught to perform self-controlled early postoperative passive flexion and active extension. If extensor tendons were injured, only moderate passive motion was allowed. Active motion was begun at 3 weeks. In one patient with severed extensor tendons, active mobilization was initiated at four weeks (case 3). Most patients were from distant regions and frequent supervision of postoperative rehabilitation was not possible.
Functional results were rated according to Strickland's rating principles as excellent, good, fair, or poor (50). Ruptures yielded poor scores. A sudden decrease in the range of motion was rated as a rupture.

Table I. Summary of cases and outcomes.

Case	Injury type/ Associated injuries	Tendon[a]	Zone	Follow-up	Outcome[b]
1	Crush-avulsion/ Incomplete amputation	FPL	5	12 mo	Good
	Crush-avulsion/ Incomplete amputation	FDP 2	5	12 mo	Excellent
	Crush-avulsion/ Incomplete amputation	FDP 3	5	12 mo	Excellent
2	Ragged/ Complete amputation	FDP 4	3	11 mo	Poor
3	Ragged/ Complete amputation	FPL	T3	19 mo	Good
	Ragged/ Complete amputation	FDP 2	3	19 mo	Excellent
	Ragged/ B, T, A, N	FDP 4	3	8 mo	Poor
4	Ragged/ B, T, A, N	FDP 5	3	18 mo	Poor
5	Ragged/ B, T, A, N	FPL	T3	11 mo	Fair
	Ragged/ B, T, A, N	FDP 2	4	11 mo	Good
	Ragged/ B, T, A, N	FDP 3	4	11 mo	Excellent
	Ragged/ B, T, A, N	FDP 4	4	11 mo	Good
	Ragged/ B, T, A, N	FDP 5	4	11 mo	Fair
6	Ragged/ B, T, A, N	FDP 3	3	6 mo	Excellent
7	Ragged/ B, T, A, N	FDP 3	2	8.5 mo	Poor
	Ragged/ B, T, A, N	FDP 4	2	8.5 mo	Poor
8	Ragged/ B, T, A, N	FDP 3	2	3.5 wk	Rupture
9	Blunt/ T, A, N	FDP 5	2	4 wk	Rupture
10	Sharp/ T	FPL	4	2.5 mo	Excellent
11	Sharp/ None	FDP 3	4	12 mo	Excellent
12	Sharp/ T	FDP 4	2	13 mo	Good

[a]Numbers indicate digit; [b]according to Strickland's rating principals (49); B: bone; T: tendon other than the evaluated one; A: artery; N: nerve.

The obtained data were statistically compared with a corresponding hypothetical set of repair results consisting of only satisfactory (excellent and good) outcomes. One-tailed Fisher's exact test was employed. The significance value was set at $p < 0.05$.

RESULTS

All sharp lesions resulted in satisfactory outcomes, most of which were achieved after tenorrhaphies proximal to the metacarpophalangeal joints (**tables I,II** and **figures 1,2**). Unsatisfactory outcomes were observed only in patients with severe complex injuries involving fractures and nerve and artery lesions (**table I**). The unsatisfactory results included two ruptures (9.5%), both of which occurred in zone 2. In case 9, the FDP repair failed during active flexion; the FDS tendon repair remained unaffected. In case 8, both the FDP and FDS tendon repairs ruptured during passive extension. Four patients underwent re-explorations because of a rupture (case 8) and adhesions (cases 2, 3, and 7).

A comparative increase in the rupture rate was statistically insignificant. The increase in both the proportion of unsatisfactory results after FDP tenorrhaphies and the overall proportion of unsatisfactory results was statistically significant (**table II**).

DISCUSSION

The presented series of flexor tendon repairs resulted in a significant proportion of unsatisfactory results after the FDP tenorrhaphies (**table II**). The unsatisfactory results may be associated not only with suture material but also with complex injuries involving irregular wounds and fractures (**table I**). Such injuries are usually contaminated and do not allow intensive postoperative mobilization. Because of these factors, limited number of repairs, and varying levels of injury, it is not possible to compare the achieved functional results with those of standard flexor tendon repair studies, which mostly include sharp lesions. However, the proportion of ruptures, which appears to be statistically insignificant, carries a comparative value. This can be further demonstrated by the following

Table II. Distribution of the outcomes according to the location of injury and the results of a statistical comparison with ideal outcomes of a corresponding hypothetical series of repairs.

Outcome	Tendon (injury zone)			Total
	FPL (zones T3, 4, 5)	FDP (zone 2)	FDP (zones 3, 4, 5)	
Excellent	1	0	6	7
Good	2	1	2	5
Fair	1	0	1	2
Poor	0	2	3	5
No ruptures / ruptures	4 / 0	3 / 2[1]	12 / 0	19 / 2[2]
Satisfactory[a] / unsatisfactory[b]	3 / 1[3]	1 / 4[4]	8 / 4[5]	12 / 9[6]
Ideal ratio of satisfactory to unsatisfactory	4 / 0	5 / 0	12 / 0	21 / 0

[a]Satisfactory = Excellent + Good; [b]Unsatisfactory = Fair + Poor + Ruptures; [1]p = 0.22; [2]p = 0.24; [3]p = 0.5; [4]p = 0.024; [5]p = 0.047; [6]p = 0.0007.

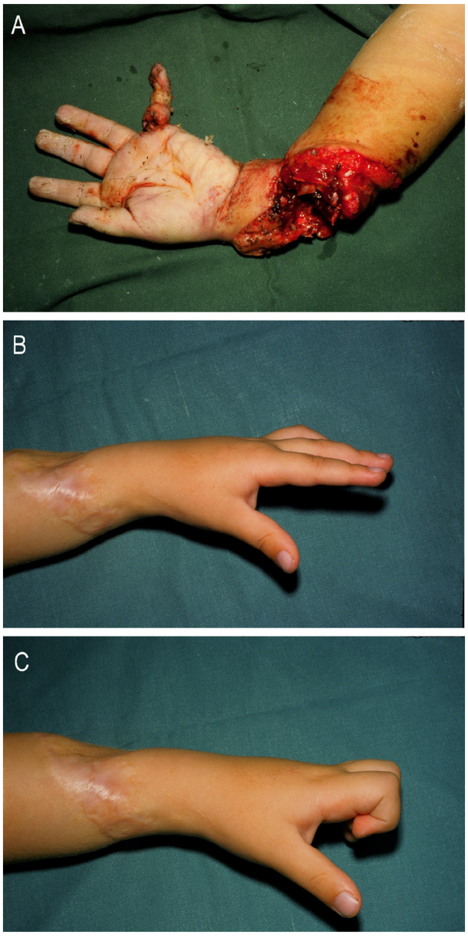

Figure 1. A case of flexor tendon repair with a 4-0 Vicryl in a complex crush-avulsion injury (case 1).

Preoperative view **(A)**; revision amputation of the little finger was performed. Active extension **(B)** and active flexion **(C)** of interphalangeal joints at 12 months. The lack of active flexion at the metacarpophalangeal joints (due to incomplete intrinsic muscle recovery) was not taken into account in accordance with Strickland's rating principals (50).

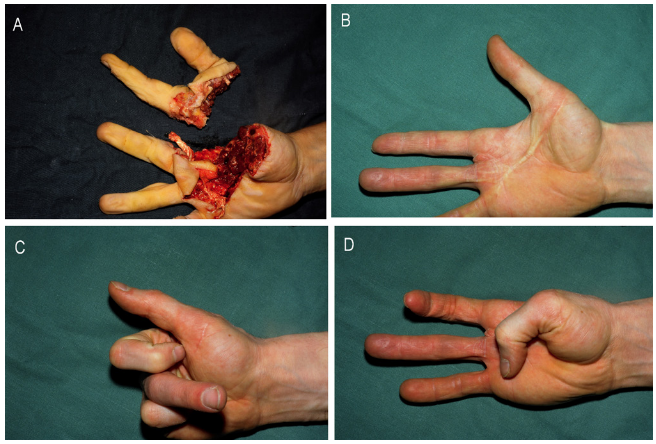

Figure 2. A case of flexor tendon repair with a 4-0 Vicryl in a complex circular saw injury (case 3).

Preoperative view **(A)**; the index finger was replanted in the middle finger position. The FDP tendon of the ring finger was repaired with a 3-cm interposition graft. Tenolysis of the grafted tendon was performed at 8 months because of a 6-cm flexion deficit. The graft was inadvertently divided in zone 2 during the procedure. Subsequent one stage grafting also failed. The patient refused further re-exploration. Active extension of the digits **(B)** and active flexion of the fingers **(C)** and of the thumb **(D)** at 19 months.

logic, which is designed to clarify whether weakening of the suture material might have caused the ruptures.

Strickland (40, 51) has crystallized data of a large number of studies into conservative working numbers in grams for the forces exerted on flexor tendons and for the strength of tendon repairs with non-absorbable sutures at various postoperative periods. To avoid underestimation of the strength of the two-strand repair in the present study, Strickland's conservative numbers for six-strand repair could be used. These numbers (as shown in Strickland's relevant table (40)) are approximately 5,400, 4,000, and 6,480 grams immediately, at three weeks, and at six weeks after repair, respectively. Thus, the approximate gain in strength due to healing at six weeks is 1,080 grams (6,480 minus 5,400). It follows that the estimated strength of four strand Vicryl 2-0 tenorrhaphies at six weeks is about 1,080 grams, because Vicryl 2-0 sutures lose all their holding strength at six weeks after incubation in rat soft tissue (36), as well as in synovial fluid (52). According to Strickland, light grip at six weeks generates a tensile stress of about 1,500 grams within a tendon repair (40, 51), which exceeds almost by one-third the estimated Vicryl repair strength (**figure 3**). Obviously, this difference would be even larger if Strickland's conservative number for two-strand repair were used. It follows that at six weeks all tendon repairs in the presented cases were destined for inevitable failure. In the light of this conclusion, the obtained incidence of ruptures can be regarded as low, and it is doubtful that the cause of the tenorrhaphy failures is due to the progressive weakening of the suture material. This echoes with the paradox of the pull-out wire repair: tendons usually do not rupture after the wire is removed at three weeks (1). The following factors can account for this conundrum:

1. Muscle weakness after prolonged limited activity and patient's caution in performing hand motion may prevent overload of the repair site. This may also be supported by the continuing successful use of absorbable sutures in Achilles tendon repairs (53), including absorbable bone anchors (54). Notably, most ruptures occur because of patient's noncompliance (48). This accounts well for the rupture that occurred during passive extension (**table I**, case 8), which is not allowed during early mobilization.
2. Adhesion formation may reduce the risk of rupture. Tenorrhaphies seem to fail after the adhesions are disrupted (55). Adhesions immobilize the tendon and thus protect the juncture from overload. However, adhesions may also have an opposite effect if they hold only the tendon part distal to the juncture and thus produce overload of the repair during active motion.
3. Hypotrophic tendon milieu may slow down degradation of sutures. Unfortunately, no studies could be found to explore dynamics of Vicryl degradation in tendons.
4. Polyglycolic acid may have properties that promote tendon regeneration. PGA-based scaffolds have successfully been used in tendon engineering (56-60). PGA degradation products (glycolic acid) may produce cellular activation, as has been shown with macrophages (61). Relevant tendon regeneration-targeted research could provide more definitive information.
5. Mobilization increases tendon repair strength. This phenomenon has been demonstrated by a number of researchers (40, 62) and has a substantial basic research support (63, 64). Most of this kind of studies appears to have involved non-absorbable suture material (65-68). Suture technique does not seem to have a considerable effect on the beneficial effects of flexor tendon mobilization (68). There is a lack of comparative studies on the effects of mobilization after tendon repair with non-absorbable and absorbable tendon suture. However, specifically relevant to the current report is an elegant study by Cao *et al.* (58) who demonstrated tensile strength increase in loaded engineered chicken tendons that were grown on scaffolds of unwoven PGA fibers seeded with tenocytes. Longitudinal load of such scaffolds also appeared to contribute to development of normal tendon structure (56-58). Furthermore, similar results have been achieved with PGA fibers seeded with human dermal fibroblasts (69) and adipose derived stem cells (70). Conjecturally, Vicryl within a tendon may be spontaneously seeded with tenocytes and thus eventually produce a neo-tendon and strengthen repair. Experimental confirmation of this supposition would imply that tendon repair with Vicryl may have a significant advantage over other synthetic sutures that lack a PGA component.

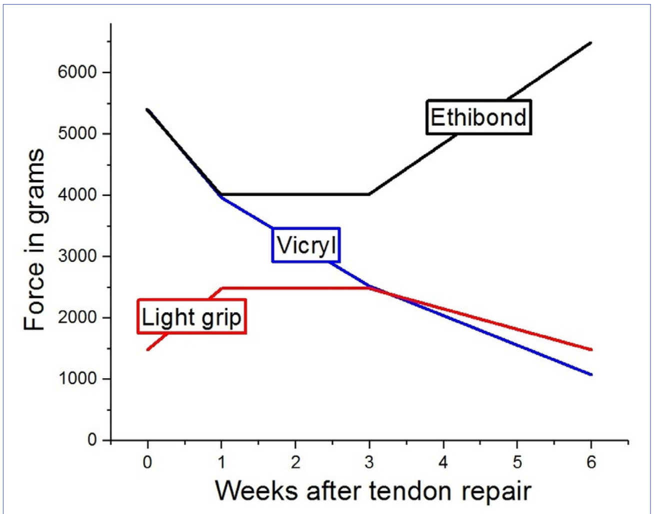

Figure 3. Approximate dynamics of six-strand flexor tendon repair strength *versus* grip strength.

The incremental loss of strength of the repair with Vicryl suture was arithmetically calculated by considering the gain in Ethibond repair strength as a tendon healing strength (see also the text). Ethibond is given as a representative of non-absorbable sutures. Adapted and modified from Strickland (40, 51).

It is noteworthy that rupture of suture material itself may occur not only because of biodegradation in the tissue but also because of possible suture weakening during storage. The author's experience is that even non-absorbable sutures, before their expiry time, may be of inadequate strength. A good practice is to test the suture strength manually.

An important advantage of absorbable sutures is that after dissolution they cease to incubate microbes (71), which may account for relatively high resistance to infection of absorbable threads (72). Notably, glycolic acid has been observed to exhibit bacteriostatic and bactericidal activity *in vivo* and *in vitro* (73). Fibrous structure of Vicryl allows its impregnation with therapeutic substances, which can be released in the course of suture degradation (59).

Inflammatory reaction to a bsorbable sutures in tendons may be a matter of concern (14, 18, 20, 74). However, because of relatively quick degradation, inflammatory response to absorbable sutures is shorter than that to non-absorbable ones. This may be one of the reasons for varying inflammatory molecular-level effects within different absorbable (74) and non-absorbable sutures (75). Notably, tendon repair with non-absorbable sutures may produce chronic inflammation and granulomas (76, 77). In general, PGA-based materials have a good biocompatibility (78, 79) because their degradation primarily occurs by hydrolysis rather than via cellular processes. Functional outcomes of tendon junctions may be more dependent on suture technique and postoperative rehabilitation than on suture material: silk, a natural material of poor biocompatibility (80), not long ago was regarded as a good suture, use which good results of tendon repair were achieved (81).

A considerable weakness of the current study is the limited number of cases, which has been attempted to overcome with a novel improvised statistical approach. Inclusion of anatomo-functionally different flexor tendons, different levels of injury, varying size of sutures, and purely controlled mobilization are additional drawbacks. Hopefully, these limitations will encourage further relevant well-designed studies.

CONCLUSIONS

Very few studies have explored tendon repair with fast-absorbable sutures. The current report indicates that Vicryl suture may withstand moderate early postoperative mobilization after hand flexor tendon repair. However, the high overall fraction of unsatisfactory results, even though this may be due to the complexity of injuries, suggests cautiousness in tenorrhaphies with fast-absorbable sutures. Although theoretical considerations suggest that fast-absorbable sutures may be beneficial in hand tendon surgery, more experimental research is needed to clarify the relationship between temporal dynamics of tendon repair and that of tensile strength of fast-absorbable sutures.

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None.

DATA AVAILABILITY

Data are provided in the current study.

CONTRIBUTIONS

VM contributed entirely to this work.

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The presented cases were managed by the author from 1999 till 2001 at Vilnius University Hospital.

CONFLICT OF INTERESTS

The author declares that he has no conflict of interests.

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