In vitro and *in vivo* Studies of the Extent of Electrothrombotic Deposition of Blood Elements on the Surface of Electrolytically Detachable Coils

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Summary

Endovascular treatment of intracranial aneurysms with electrolytically detachable coils is often claimed to be based on electrothrombosis, i.e. intra-aneurysmal thrombus formation through applied direct current. Despite the fact that this concept was described more than a century ago, the significance of electrothrombosis in the endovascular treatment of aneurysms remains debatable. Apart from electrothrombosis, mechanical obliteration of the aneurysmal lumen might be one of the many possible mechanisms to explain why and how detachable coils are effective in preventing aneurysms from (re-)rupture. The purpose of this experimental study was to investigate to what extent direct current comparable to that used for coil detachment would influence the adhesion of cellular and liquid blood components to the surface of electrolytically detachable platinum coils.

For the *in vitro* study, electrolytically detachable platinum coils of various types were exposed to stagnant heparinised blood for a total of 16 h, without or with applied direct current for 30 or 90 s (1 mA, 4-6 V, coil as anode). For the *in vivo* study, electrolytically detachable platinum coils were exposed to flowing blood for 180 s, without or with applied direct current (2 mA, 4-6 V, coil as either anode or cathode), with-

out anti-coagulation and after intravenous administration of 5000 U Heparin and again after the intravenous administration of 500 mg Aspirin in addition to Heparin. After exposure to blood according to these different experimental protocols, the coils were fixed in formalin solution, gold coated and examined by scanning electron microscopy.

Thrombus formation on the surface of all unfibred coils was thin and highly variable both from coil to coil, and on different areas of any given coil. The application of direct current minimally enhanced thrombus formation in stagnant blood *in vitro*, but not *in vivo*. The cellular and fibrin adhesions on the coil surfaces without and with applied current did not effectively increase the diameter or volume of unfibred coils. Coils with attached nylon fibres, however, proved to be highly thrombogenic without or with application of current. In fibred coils, surface adhesions without and with applied current were voluminous enough to effectively increase the diameter of the coil, potentially important for the process of endosaccular aneurysm occlusion.

Electrothrombosis plays no role in the endovascular treatment of intracranial aneurysms with electrolytically detachable coils. This explains why platinum coils with non-electrolytic detachment mechanisms show a similar efficiency and recurrence rate.

Introduction

During the last decade, endovascular coil occlusion of intracranial aneurysms has matured into a widely accepted treatment modality. While reported acute results are at least as good as most neurosurgical series, long-term occlusion rates and incidences of recurrent haemorrhage leave some space for further improvement¹.

It has been widely assumed that part of the effectiveness of endovascular occlusion of intracranial aneurysm is due to electrothrombotic deposition of blood elements on the surface of the coils. The recent availability and demonstrated effectiveness of coils detached by mechanisms (mechanical, hydrodynamic, thermal) which cannot cause electrothrombosis, and a review of historical studies, suggest that this widely held assumption might not be true.

The purpose of this investigation was to further evaluate the significance of electrothrombosis during the electrolytic detachment of coils. Two different experiments were carried out to assess the degree of blood-derived surface adhesions on electrolytically detachable platinum coils. The experimental protocol was designed to meet the following criteria:

- 1) to avoid the use of non-human blood with its associated differences in the coagulation system,
- 2) to address the different conditions of stagnant and flowing blood,
- 3) to compare the effects on adhesion of the presence and absence of application of direct current to the coils,
- 4) to compare the thrombogenicity of fibred coils with unfibred coils,
- 5) to evaluate the effects of anti-coagulation and anti-aggregation. It would have been ideal to design an experiment to control all the above mentioned factors separately. Obvious limitations of coil availability, experimentation time and evaluation capacity required the compromise described below.

Material and Methods

Source of tested coils: The coils tested in the two experiments were EDC II - (*in vivo*) or EDC II+ - (*in vitro*) systems, provided by Dendron/MTI, Bochum, Germany. These are electrolytically detachable coils, made specifically

for the endovascular treatment of intracranial aneurysms and other vascular lesions. There are some significant technical differences in the detachment mechanism between the EDC II-system and the Guglielmi Detachable Coil-system (GDC, Target Therapeutics/Boston Scientific), but both devices share the feature that the detachment mechanism is based on the application of a direct current of either one or two mA at less than 10 V. In clinical practice, EDC II and EDC II+ coils are detached after an average of 30 s. During this detachment time, the direct current applied to the insertion system is transmitted to the platinum coil and might therefore eventually induce electrothrombosis.

Part I: *in vitro* experiment

An in-vitro experiment on electrothrombosis in stagnant blood was performed using the technique described by Padolecchia et al². Eight ml of sterile heparinised full blood at 37°C were placed in glass specimen tubes with a cathode of stainless steel mounted on the inside. Three different paradigms were modelled:

- 1) The coil was exposed to stagnant blood for 16 hours without the application of current.
- 2) A positive terminal was connected to the proximal end of the coil delivery system and a negative terminal was connected to the above-described stainless steel cathode. A direct current of 1 mA was applied for 30 s using a constant-current delivery device. The coil was then exposed to stagnant blood for 16 further hours, without the application of additional current.
- 3) Protocol (2) was repeated with an application time of 90 s rather than 30 s.

This experimental protocol was repeated for:

- three unfibred 5 mm diameter, 15 cm length T10 electrolytically detachable coils
- three fibred 2 mm diameter, 6 cm length T10 electrolytically detachable coils
- three variable detachable coils (VDS) 3 mm diameter, 12 cm total length (divisible into four segments, each 3 cm long) T10 electrolytically detachable coils.

After retrieval from the specimen tube, the coils were gently rinsed with alcohol, formalin-fixed for 24 hours and were transferred without further manipulation onto a finishing plate for gold coating.

Figure 1 Schematic representation of coil introducing assembly.

Part II: *in vivo* experiment

The experiment was carried out in a healthy volunteer, into whom platinum microcoils were exposed for a defined duration of 180 s to the blood stream with either:

- no applied current
- direct current with the usual polarity (anode at the proximal end of the coil delivery system), current intensity (2 mA) and voltage (4–6 V) used in clinical detachment
- the polarity of the current reversed (cathode at the proximal end of the coil delivery system).

The experimental technique was modified from that described by Ovitt et al³. The platinum coils were exposed to flowing blood in the iliac artery by positioning through an 8 French sheath through the femoral artery. The coils to be tested (2 mm helix diameter/6 cm length, T10) were placed into a tube produced from an angiographic guiding catheter (8 French guiding catheter, ITC/Boston Scientific, figure 1). The cut end of the tube was open. The hub end of the tube was sealed to prevent blood leaking out during the exposure of the coil. The whole assembly was sterilised before introduction through the femoral sheath. The coil to be exposed was positioned within the tube, near the open end, with side-holes cut by laser near the open end to ensure the coil was surrounded by flowing blood. The length of the tube was chosen so that several cm protruded beyond the sheath.

The duration of exposure to the experimental condition within the sheath was 180 s. Where current was applied, the duration of application was determined by coil detachment, indicated by the detachment system. If there was no evidence of coil detachment, current was applied for the full 180 s. It should be noted that with this coil system in clinical use at these parameters of voltage and current, detachment invariably occurs in less than one minute, typically at approximately 30 seconds. This is often not accompanied by an indication from the constant-current delivery device.

In order to mimic the conditions of stagnant blood within a partially coiled aneurysm, 10 coils were exposed to flowing blood for 5 s, then the tube containing the coils was withdrawn into the sheath, covering the side-holes. The coil was then left in the sheath for 180 s with blood stagnation.

In order to explore the effect of anti-coagulation and anti-platelet agents;

- 21 experiments were performed without any systemic anti-coagulation
- 15 experiments were performed after intravenous administration of 5000 units of Heparin
- 19 experiments were repeated one hour after intravenous administration of Heparin with the additional intravenous administration of 500 mg Aspirin®, an injectable form of Aspirin, acting as an anti-aggregation agent.

Several possible combinations of current vs. no current, unfibred vs. fibred coils, anti-coagulation vs. no anti-coagulation and flow vs. stagnant blood were explored. In addition, studies were performed with reverse polarity (cathode attached to coil delivery system) of the detachment current with unfibred coils only.

After exposure to the blood in the appropriate experimental circumstances, the tube was removed from the sheath and the part containing the coil was cut from the remainder and placed in 4% formalin solution for 24 hours. The tubes were removed from the formalin solution, opened with a scalpel along their longitudinal axis, the coil and any contained thrombus were transferred without further manipulation onto a finishing plate for gold coating.

Examination of coils from both in vitro and in vivo blood exposure

Scanning electron-microscopic examination was conducted utilising a standard gold-coating technique³⁻⁷. The coils were examined at magnifications of x20, x200 and x1000 and documented by photography. For the purpose of this paper, the x200 magnifications were chosen for illustrations as a compromise between detailed demonstration of adherent material and an overview of the coil mass. Selected x20 images have been provided for an overview.

The results are based on joint visual evaluation and consensus of the participating authors (HH, SB, IT). For most coils studied, there was considerable variability in the density of adherent material from region to region. For each experimental setting, the images chosen were those with the highest degree of adhesion of cellular elements and fibrin.

The degree of deposition of cellular elements of blood and fibrin on the coil surface was assessed visually and graded into:

– <i>bare</i>	(essentially devoid of adherent material)
– <i>sparse</i>	(thin coat of adherent material, insufficient to fill grooves on coil surface)
– <i>moderate</i>	(sufficient volume of adherent material to fill grooves on coil surface)
– <i>dense</i>	(coil surface largely obscured)
– <i>coated</i>	(coil surface completely obscured with sufficient material to significantly alter effective diameter)

In addition, it was noted if the coverage was *patchy* or *confluent*.

Results

The visual evaluation and comparison of the photographs from scanning electron microscopy revealed the following results.

Part I: in vitro experiment (figure 2)

The fibred coils had significantly more adherent material than the non-fibred coils. This effect was considerably greater than the difference between the current levels within any group. With or without the application of current, for fibred coils the deposition was not confined to the region of the fibres; the coil surface was generally obscured and the effective diameter was often increased by a thick coat of adherent cellular blood elements and fibrin.

The VDS™ coils had more adherent material than the standard non-fibred coils, but much less than the fibred coils. The VDS™ 90 s group exhibited more marked variability from site to site on the coil surface than any other group, perhaps related to the different detachment zones.

Table 1 **In vitro experiment**

anti-coagulated, stagnant blood	unfibred, 5 mm, 15 cm	fibred, 2 mm, 6 cm	unfibred, 3 mm, 12 cm, VDS™
no current	bare-sparse (patchy)	sparse-dense (patchy)	bare-moderate (patchy)
30 s current	bare-sparse (patchy)	sparse-dense (confluent)	bare-moderate (variable)
90 s current	sparse-moderate (variable)	moderate-coated (confluent)	bare-coated (confluent, highly variable)

A) no current

B) 30 sec 1 mA DC

C) 90 sec 1 mA DC

• *anti-coagulated, stagnant blood, unfibred 5 mm, 15 cm T10 EDC II+ coils:* A) no current: bare-sparse (patchy); B) 30 sec, 1 mA DC: bare-sparse (patchy); C) 90 sec, 1 mA DC: sparse-moderate (patchy, confluent), greater than A or B.

D) no current

E) 30 sec 1 mA DC

F) 90 sec 1 mA DC

• *anti-coagulated, stagnant blood, fibred 2 mm, 6 cm T10 EDC II+ coils:* D) no current: sparse-dense (patchy); E) 30 sec, 1 mA DC: sparse-dense (confluent); F) 90 sec, 1 mA DC: moderate-coated (confluent), more than D or E.

G) no current

H) 30 sec 1 mA DC

I) 90 sec 1 mA DC

J) 90 sec 1 mA DC

• *anti-coagulated, stagnant blood, unfibred 3 mm, 12 cm, 4x3 cm segments VDS-EDC II+-T10:* G) no current: bare-moderate (patchy); H) 30 sec, 1 mA DC: bare-moderate (patchy, confluent); I, J) 90 sec, 1 mA DC: bare-coated (confluent, highly variable). In J) note the high variability of the extent of surface adhesions in coils, in this example after application of a DC of 4-6V, 1 mA for 90 sec. Adjacent loops of the same coil are either bare or almost coated.

Figure 2 Photo documentation of in vitro experiments (heparinised stagnant blood) on electrothrombosis (16 hrs of exposure for each coil). Representative findings at a magnification factor of x200 (A-J). Overview of the complete coil is best provided at a magnification of x20 (K-O).

K) no current

L) 30 sec 1 mA DC

M) 90 sec 1 mA DC

K,L,M) low magnification (x20) pictures of bare coils (5 mm/15 cm) after blood exposure without DC application (K), with application of 4-6 V, 1 mA for 30 sec (L) and for 90 sec (M). With current application to bare coils, there has not been sufficient deposition to increase the effective coil diameter.

N) no current

O) 30 sec 1 mA DC

After blood exposure of a fibred coil without DC application (N), thick adhesions occur on the coil surface and between the fibres. The amount of cellular and fibrin adhesions is essentially the same after application of 4-6 V, 1 mA DC for 30 sec (O). In both cases, the effective diameter of the fibred coils has significantly increased.

Part II: in vivo experiment (figure 3)

In general, there was slightly more adherent material on the *in vivo* exposed coils. Since this was also true for those coils exposed to the blood stream without direct current, it seems probable that this finding is related to the constant supply of platelets and fresh fibrin through flowing blood in contrast to stagnant blood in a glass tube. As in the *in vitro* experiment, the amount of thrombus adherent to the coil surface was highly variable. While the increased amount of adhesion of material of fibres was obvious, there was no significant difference in the degree of adhesion in the presence or absence of applied current. In the setting which resembles mostly the conditions of clinical treatment (Group 2, unfibred coils, anti-coagulation with Heparin), only sparse surface adhesions were found and no electrothrombotic effect was verified.

Paradoxically, all coils of Group 3 (anti-coagulation with 5000 U Heparin IV and 1 h later, anti-aggregation with 500 mg Aspirin IV) showed significantly denser coverage than the comparable Group 1 (no anti-coagulation) or Group 2 (anti-coagulation with 5000 U He-

parin IV) coils. Again, there was no electrothrombotic effect.

In the *in vitro* experiments there was in general less adhesion than in the *in vivo* experiments, perhaps due to the fixed supply of substrates within the volume of the tube, in contrast to the constant supply in flowing blood. On the other hand, there was still more deposition, even in stasis, *in vivo* than *in vitro*. The only observable effect of the application of current occurred in the *in vitro* experiments with a duration of 90s, longer than the average detachment time of 30s for this coil system in clinical use. Under all other circumstances examined, the application of current, including reverse polarity, had no consistent effect. Fibred coils produced far greater adhesion than unfibred coils. This effect dominated all others.

Discussion

The intimal surface of an intact blood vessel shows a negative charge with respect to the adventitial surface of that vessel⁸. The cellular blood components also have a negative charge on their surface and are therefore repelled by

the intact vessel wall. Placement of a positive electrode into the lumen decreases the repulsion of the cellular elements and therefore promotes thrombosis^{9,10}. The amount of induced thrombus is dependent on the applied direct current intensity and the duration of application¹¹⁻¹⁵. Its formation is opposed by Heparin¹¹.

This process should be contrasted with electrocoagulation where a temperature rise is induced by the supply of electric current (for example high-frequency alternating current) to cause thermal damage to blood components and the vessel wall. In electrothrombosis, coagulation is induced exclusively by bio-electric mechanisms.

In the past, electrothrombosis has been used by many authors to treat extracranial aneurysms

after direct puncture and insertion of various amounts and types of wire¹⁶⁻²⁷. Application of these principles to an intracranial aneurysm is credited to Blakemore et Al¹⁷ and Werner et Al²⁸.

Some of the underlying principles of current coil-occlusion techniques, based on surgical aneurysm exposure, had been described in detail by Mullan et Al²⁹. Piton et Al³⁰⁻³² had already developed fundamentals for an endovascular electrothrombotic treatment of intracranial vascular lesions, which never came to clinical practice at that time. After a latency period of more than a decade, the renaissance of electrothrombosis started with the publications of Guglielmi et Al^{33,34}.

The principle of the system named after him can be summarized as follows. Endovascular

Table 2 **In vivo experiment**

Group 1	–	–	–
No Anti-coagulation		unfibred, 2 mm, 6 cm T10	fibred, 2 mm, 6 cm T10
flowing blood	no current	sparse-moderate	moderate (patchy)
–	2 mA, ≤180s	sparse-moderate	moderate (patchy)
–	reverse current	bare-sparse	–
stagnant blood	no current	moderate (confluent)	–
–	2 mA, ≤180s	moderate (confluent)	–
Group 2	–	–	–
5000 U Heparin IV	–	unfibred, 2 mm, 6 cm T10	fibred, 2 mm, 6 cm T10
flowing blood	no current	sparse-moderate (variable)	moderate-dense (variable)
–	2 mA, ≤180s	sparse-moderate (variable)	moderate-dense (variable)
–	reverse current	sparse-moderate (variable)	–
Group 3	–	–	–
5000 U Heparin + 500 mg Aspisol®	–	unfibred, 2 mm, 6 cm T10	fibred, 2 mm, 6 cm T10
flowing blood	no current	sparse-moderate-dense (confluent)	moderate-dense (confluent)
–	2 mA, ≤180s	sparse-moderate-dense (confluent)	moderate-dense (confluent)
–	reverse current	sparse-moderate-dense (confluent)	–
stagnant blood	no current	sparse-coated (confluent)	–
–	2 mA, ≤180s	sparse-coated (confluent)	–

Group I: No Anti-coagulation

A) no current

B) 2 mA DC

C) reverse current

• **flowing blood, no anti-coagulation, unfibred** 2 mm, 6 cm T10 EDC II coil: A) no current: sparse-moderate; B) 2 mA DC: sparse-moderate; C) reverse current, 2 mA DC: bare-sparse, less than A or B.

D) no current

E) 2 mA DC

• **flowing blood, no anti-coagulation, fibred** 2 mm, 6 cm T10 EDC II coil: D) no current: moderate (patchy); E) 2 mA DC: moderate (patchy).

F) no current

G) 2 mA DC

• **stagnant blood, no anti-coagulation, unfibred** 2 mm, 6 cm T10 coil: F) no current: moderate (confluent), G) 2 mA DC: moderate (confluent).

Group 2: Anti-coagulation with 5000 U Heparin IV

H) no current

I) 2 mA DC

J) reverse current

• **flowing blood, anti-coagulation, unfibred** 2 mm, 6 cm T10 EDC II coil: H) no current: sparse-moderate (patchy, confluent); I) 2 mA DC: sparse-moderate (patchy, confluent); J) reverse current, 2 mA DC: sparse-moderate (patchy, confluent).

K) no current

L) 2 mA DC

• *flowing blood, anti-coagulation, fibred* 2 mm, 6 cm T10 EDC II coil: K) no current: moderate-dense (patchy, confluent), L) 2 mA DC: moderate-dense (patchy, confluent).

Group 3: Anti-coagulation with 5000 U Heparin IV and 1 hr later, Anti-aggregation with 500 mg Aspirin IV

M) no current

N) 2 mA DC

O) reverse current

• *flowing blood, anti-coagulation, anti-aggregation, unfibred* 2 mm, 6 cm T10 EDC II coil: M) no current: sparse-moderate-dense (confluent); N) 2 mA DC: sparse-moderate-dense (confluent); O) reverse current, 2 mA DC: sparse-moderate-dense (confluent)

P) no current

Q) 2 mA DC

• *flowing blood, anti-coagulation, anti-aggregation, fibred* 2 mm, 6 cm T10, EDC II coil: P) no current: moderate-dense (confluent); Q) 2 mA DC: moderate-dense (confluent).

R) no current

S) 2 mA DC

• *stagnant blood, anti-coagulation, anti-aggregation, unfibred* 2 mm, 6 cm T10, EDC II coil: R) no current: sparse-coated (confluent), S) 2 mA DC: sparse-coated (confluent).

Figure 3 Photo documentation of in vivo experiments (flowing or stagnant blood) on electrothrombosis (3 min of exposure for each coil). Representative findings at a magnification factor of x200.

treatment of an intracranial saccular aneurysm can be achieved by entering the aneurysmal sac with a microcatheter, and filling this sac with platinum coils. These coils are welded to an insertion wire, from which they are detached by application of a direct current to the wire. This direct current is transmitted to the platinum coil and is supposed to cause electrothrombosis on the coil-surface during the detachment process.

While the clinical efficiency of this device is beyond doubt¹, a long-standing controversy has focused on the actual role of electrothrombosis. Criticisms concern the fact that the experimental observations on which the concept was finally based had been made in various animal models, mainly in pigs. The coagulation systems of these animals differ greatly from human coagulation and the tendency to spontaneous thrombosis of surgically created pouches stands in clear contrast to the natural history of human aneurysms^{3,7,35-43}.

Much of the historical work on electrothrombosis was performed on extracranial and intracranial aneurysms or vessels using parameters, materials and application times completely different from those now used for the endovascular treatment of intracranial aneurysms^{11-16,44-62}.

With these publications in mind, it would appear that at a current intensity of 1-2 mA and a voltage of 4-10 V, an application time of far longer than 30-40s would be necessary to induce significant endovascular electrothrombosis.

The potential role of electrothrombosis for the treatment and healing of an aneurysm is also debatable:

- The therapeutic value of intra-saccular thrombus formation is not proven^{63,64}.
- Effective coil systems exist that do not allow any electrothrombosis⁶⁵⁻⁶⁹.
- Electrothrombosis without complete filling of the lumen of the vascular structure concerned have in general not resulted in effective exclusion of the lumen^{50,51,70}.
- In clinical conditions, the amount of thrombosis occurring on the surface of freshly inserted electrolytically detachable platinum coils is probably so small that it is quantitatively unimportant in terms of volume of the aneurysm lumen filled. For this reason, maximal dense filling of the aneurysm is necessary^{4,5,43,71,72}.

For the process of morphological cure of an aneurysm, the formation of early intra-aneurysmal thrombus is neither necessary nor sufficient. The following steps may be postulated:

- the formation of a new intima at the ostium of the aneurysm^{66,72}
- resorption of any unorganised intra-aneurysmal thrombus^{35,73,74}
- the formation of scarring-fibrous connective tissue between the coil-loops^{75,37}
- reactive thickening of the aneurysm wall^{35,76,77}.

The experiments of Sorteberg et Al^{78,79} explain the effective mechanism of coil occlusion of intracranial aneurysms through haemodynamic modifications within the aneurysm lumen. The fact that an effect on blood flow was demonstrable after the incorporation of only one coil argues for a haemodynamic effect of the coils.

There are obvious shortcomings in our experimental design.

In the *in vitro* experiments, all effects related to flow are completely excluded. In clinical practice coiling begins in flowing blood, aiming for stasis while in this experimental setting this clinical endpoint is present from the start. This presumably has both positive and negative effects on the process of adhesion on the coils surface; stasis will favour adhesion, but on the other hand the supply of adhesive material is limited whereas in flowing blood there is a constant supply. The time of exposure (16 hours) was arbitrary. It is sufficiently long for autolysis to have already begun. Different coil sizes were used for different groups.

In the *in vivo* experiments, the flow conditions in the tube/sheath system are unlikely to match those seen in aneurysms. The surface of the tube/sheath system may have influenced the local environment in a way that alters coagulation, in an uncontrollable way. The anti-aggregation agent (Aspisol) was administered in a repetition of the experiment one hour after the anti-coagulation with Heparin had been administered for the Group 2 experiments. This almost certainly means that the level of anti-coagulation was lower in the anti-coagulation + anti-aggregation experiment (Group 3). This may partially explain the increased adhesion seen in Group 3 in comparison to Group 2. What is more puzzling is the presence of more

adhesion in Group 3 than in Group 1 (No anti-coagulation). These observations would appear to suggest that Aspisol somehow enhances adhesion to coil surfaces, the opposite effect to that desired. There are several confounding factors; these experiments were performed after the subject had been exposed to stress for longer, a factor known to influence coagulation and platelet adhesion⁸⁰.

In both sets of experiments, thrombus may have been washed off the coil surfaces in the process of preparation for electron-microscopy. The evaluation of the degree of adhesion to the coil surface by visual assessment of scanning electron microscopic images is to some extent an arbitrary process. An apparently quantitative result could have been yielded by various techniques such as precision-weighing coils before and after the experiment or by measuring adhesion thickness directly or coil volume by immersion. Given the variability observed between samples in this study, a large sample size would probably be necessary to yield meaningful quantitative results.

Nonetheless, despite the high variability between samples, some useful observation can be made.

In the *in vitro* experiments there was in general less adhesion than in the *in vivo* experiments, perhaps due to the fixed supply of substrates within the volume of the tube, in contrast to the constant supply in flowing blood. On the other hand, there was still more deposition, even in stasis, *in vivo* than *in vitro*. The only observable effect of the application of current occurred in the *in vitro* experiments with a duration of 90s, longer than the average detachment time of 30s for this coil system in clinical use. Under all other circumstances examined, the application of current, including reverse polarity, had no consistent effect. Fibred coils produced far greater adhesion than unfibred coils.

This effect dominated all others.

Conclusions

Electrothrombosis was not observed at all in the *in vivo* experiments, or under the conditions of the *in vitro* experiments that replicate the clinical application of the EDC II system. Fibred coils promote the deposition of a significant amount of material on the coil surface, irrespective of conditions of stagnant or flowing blood, anti-coagulation or anti-platelet agents.

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