FROM THE ORTHOPAEDIC CLINIC OF THE KAROLINSKA INSTITUTET, STOCKHOLM (HEAD: PROFESSOR STEN FRIBERG)

AN EXPERIMENTAL ATTEMPT TO REPLACE MUSCLE FUNCTION BY ELASTIC ENDOPROSTHESES

By

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The possibility of replacing the function of a paralysed muscle or muscle-group by special internal elastic devices could be of great practical importance in a large field of orthopaedic and reconstructive surgery.

A few experimental attempts have been made earlier in this direction (Lambotte 1932, 1947, von Voelker 1934, Klages 1934, Borelli 1952), but it seems that the experience gained until now has not been considered to justify a wider application of this principle.

The present experiments were undertaken in order to study and discuss the possibilities of using elastic internal prostheses for the replacement of the function of paralysed muscles.

Given that such elastic devices may be constructed either of rubber or of metal springs or of a combination of both, the principal matters to be examined in the present work are as follows:

(a) the reaction of the living animal host tissues to the rubber, the latter acting as a foreign body,

(b) the changes which the rubber undergoes when inserted in the body and retained there for a certain period of time, by comparison with the changes which the rubber undergoes when outside it and

(c) the mechanics of the metal springs and the possibilities of combining such springs with rubber.

MATERIAL AND METHODS

Thirteen adult rabbits of a common strain were operated on. The rubber used in the present experiment was of a high quality, "695 transparent", supplied in the form of sheets 2 mm. thick.

The operations were performed under open-mask ether anaesthesia.

In an earlier[1] attempt we had tried to fix rubber bands on the skeleton of the extremities of the animals, but the results then obtained were poor, because of extensive local reactions, with swelling and suppuration, which in our opinion were due to the thin layers of tissue above the disproportionately large prostheses, so that a satisfactory closure of the operative wounds could not be obtained.

In the present series the dorsolumbal spine of the animals was operated on and in all cases the overlying thick muscular layer secured a very good healing of the wounds.

By an incision of the skin 5–8 cm. long, the spine was exposed from the sacrum up to the lower thoracic spinal processes. The crista ilica was freed, on the one side, from the muscle insertions and a hole was bored through the iliac bone. Similarly the spinal process of one of the lower thoracic vertebrae was dissected free from the surrounding soft tissues.

A rubber strip, 0.5–1 cm. wide and 10–15 cm. long, was pushed through the hole in the iliac bone. The two ends of the rubber strip were then, with the aid of a long forceps, driven, through a canalisation under the muscles, upwards toward the selected spinal process and fixed round it, tied by a knot, the rubber being stretched sufficiently to produce a severe to moderate scoliosis. In order to obtain a better fixation the rubber band was also secured by a short length of stainless-steel wire tied round the spinal process (fig. 1).

No fixation of the spine, of any kind, was applied postoperatively.

In all the animals an injection of 150,000 I.U.-penicillin was given immediately after the operation.

RESULTS

The postoperative course was in all cases without complication and the wounds healed by first intention. All the animals showed some discomfort immediately after the operation but they behaved quite normally a few days later.

Two animals (nos. 4 and 11) died about five weeks after the operation. In the first case the death was probably due to an extensive suppuration and abscess formation all round the iliac bone. In the other case the cause of death could not, reasonably, be related to the operation itself.

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[1] A first attempt in this investigation was made as early as June 1951.

TABLE I

Experiment no.	Time of observation (days)	Functional late results obtained by the operation	Remarks
1	477	None	
2	608	Moderate scoliosis	
3	461	None	
4	33	None	Suppuration. Death probably
5	456	None	due to it.
6	454	None	
7	454	None	
8	367	None	
9	498	Very severe scoliosis	
10	365	None	Isolated abscess formation.
11	37	None	Death not related to operation.
12	352	None	
13	484	Moderate scoliosis	

The remaining 11 animals were sacrified 352 to 608 days after the operation. No complications of any kind were observed in them throughout the period of observation (Table I).

Postmortal dissection was performed on all the animals. In two cases (nos. 4 and 10) a suppuration and abscess formation was found. In case no. 10 two well isolated walnut-sized abscesses were found under the skin without any visible communication with the operative field itself. In the remaining 11 cases no signs of any pathological reaction could be observed macroscopically.

In all the cases, the rubber band was found to be enclosed in a very thin capsule of fibrous tissue covered on the inside by a smooth membrane, and lubricated by a small amount of a highly viscous fluid. The rubber band was free and movable within this capsule. The capsule described was also found to cover inwardly the hole of the iliac bone through which the rubber band had been driven.

The rubber band was found to have slipped off the upper point of fixation in five cases (nos. 2, 4, 5, 6 and 10), off the lower point of fixation in six cases (nos. 3, 7, 7, 9, 11 and 12) and off both points of fixation in one case (no. 1). The slipping had been caused either by erosion and fracturing of the iliac crest because of the extensive stretching of the rubber band, or by fracture of the spinal process of the vertebra or by rupture of the rubber band itself. It was thus in only one case (no. 13) that permanent fixation throughout the whole period of observation was obtained.

X-ray control: We have also tried to follow up, by means of x-ray controls, the evolution of the skeletal deformity produced on the animals by the operation. It meanwhile proved difficult to secure satisfactory fixation of the rubber prosthesis in the very fragile dorsal skeleton of the rabbits without incurring unduly high expenses for special constructions. In all cases a severe scoliosis was produced by the operation, but in ten cases the deformity disappeared within the first few days. This was probably due to the rubber bands slipping at an early stage from their point of fixation, in the way described above. In only three cases (nos. 2, 9 and 13) could the scoliosis produced by the operation be followed up during the whole period of observation.

In order to study the evolution of the scoliosis after the rubber bands had been taken away, the animals in the three above-mentioned cases were operated on again 475, 365 and 350 days respectively after the first operation. It was meanwhile found during the second operation that the rubber band had already slipped off in cases 2 and 9 and only in case 13 was it found still *in situ*. The conclusion was therefore drawn that the slipping in the first two cases occurred a rather long time after the first operation and that the deformity produced was of a permanent character, even when the traction of the rubber band had ceased to exist. This conclusion was also confirmed by the fact that even in case 13 the scoliosis remained more or less unchanged 116 days after the rubber band had been taken away (figs. 2, 3, 4).

Histological examination. After the animals had been killed and the rubber band was removed the operation region was excised and fixed in 10 per cent formalin, and specimens were taken from those parts which had contained the rubber band, viz. the insertion channel in the iliac bone and the passage through muscle and fat.

Fig. 1.

Diagrammatic representation of the operative technique.

Fig. 2 a.

Case no. 2. Roentgenogram of the dorsolumbal spine taken 461 days after the insertion of the rubber endoprosthesis. A slight scoliosis still exists.

Fig. 2 b.

Same case. Roentgenogram of the spine taken immediately after the second operation—475 days after the first—where the rubber band was found to have already slipped from the upper point of fixation. The deformity of the spine persists practically unchanged.

Fig. 2 c.

Same case. Roentgenogram taken 604 days after the insertion of the rubber band. The degree of scoliosis is still unchanged.

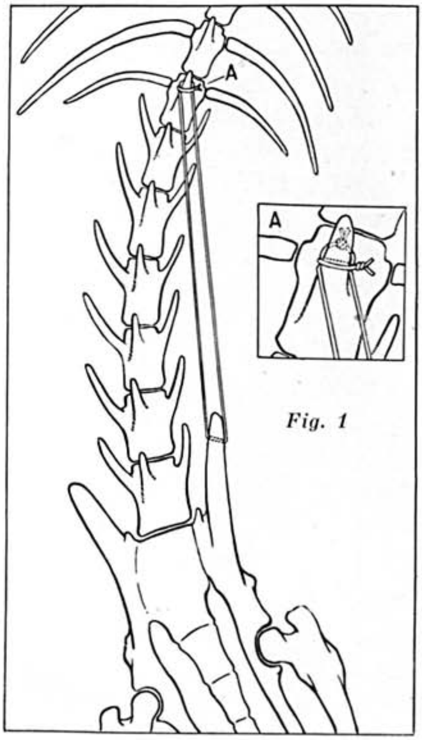
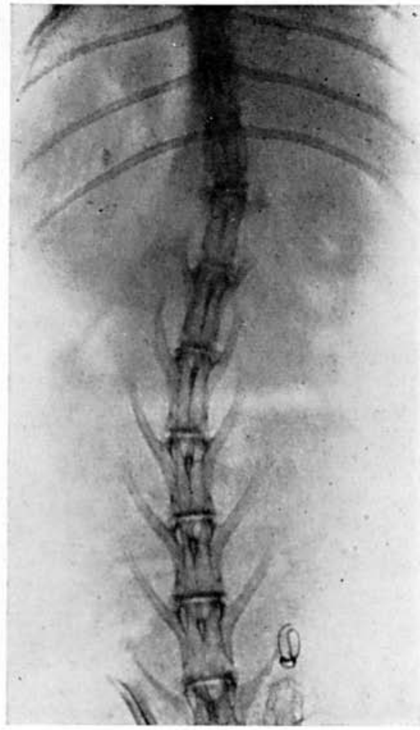
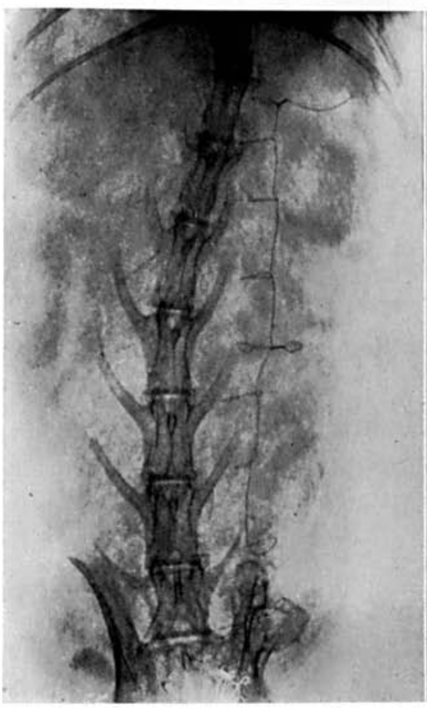


Fig. 1



a



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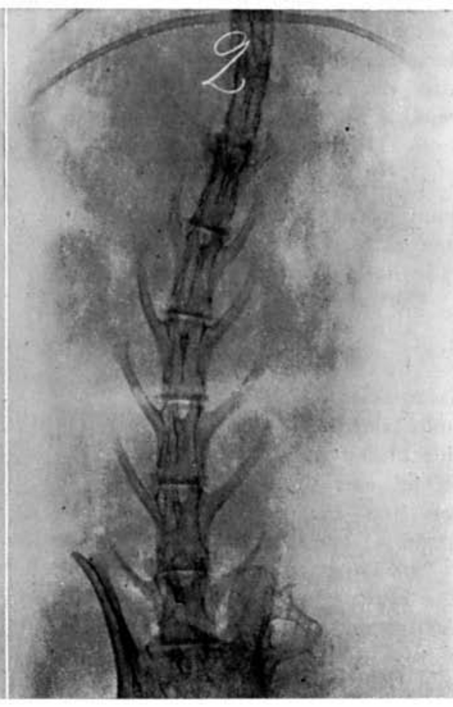

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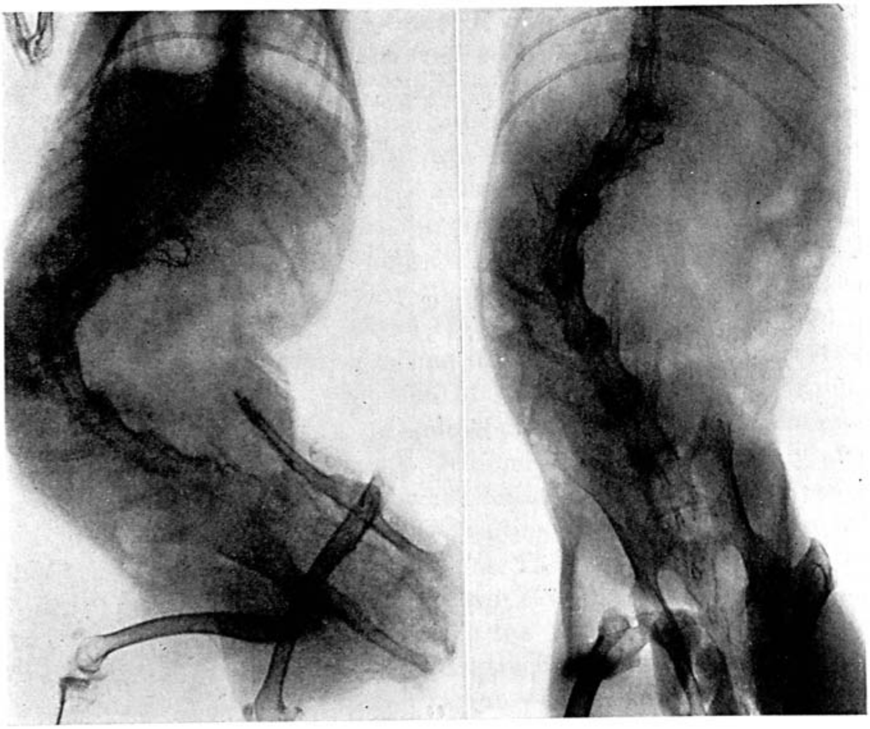
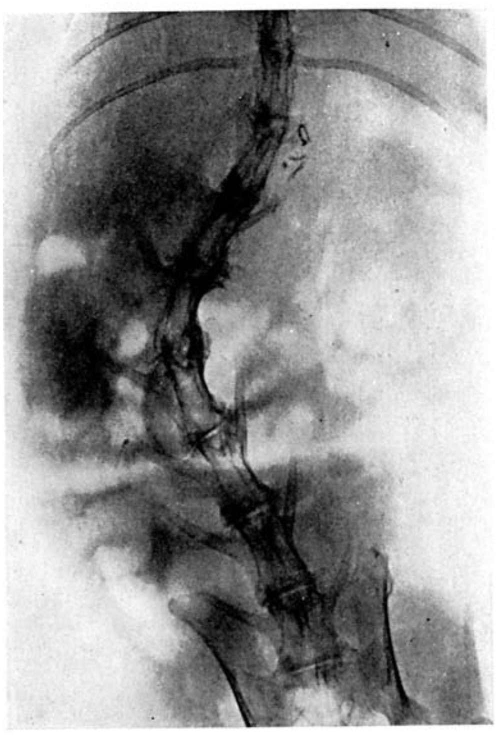


a b

Fig. 3 a.
Case no. 9. Roentgenogram of the dorsolumbal spine taken 22 days after the insertion of the rubber band. A severe scoliosis has been brought about.

Fig. 3 b.
Same case. 330 days after the insertion of the rubber band the degree of scoliosis has markedly decreased, but a severe scoliosis still persists.



c

Fig. 3 c.
Same case. Roentgenogram of the spine taken 463 days after the insertion of the rubber band. During a second operation—365 days after the first—the rubber band was found to have already slipped from its lower point of fixation.
The degree of scoliosis is here practically unchanged by comparison with the last roentgenogram (fig. 3 b).

TABLE II

Tested material	Thickness of the sample m. m.	Hardness	Modulus of elasticity kg/cm^2 at							Rupture	
			50%	100%	200%	300%	400%	500%	600%	kg/cm^2	%
Freshly prepared rubber "695" ...	2.0	25	4.0	5.0	6.1	8.8	10	12.5	17	100	1000
Same as above	4.4	25	3.0	4.1	5.8	7.4	9.2	—	—	100	400
One-year-old rubber "695"	2.0	26	2.0	4.0	6.0	8.0	10	13	22	31	650
Rubber "695" retained in the body of the animal for one year	2.0	25	2.16	3.3	5.5	7.6	12	17.4	28	30	630

Modulus of elasticity = measure of the resistance to deformation.

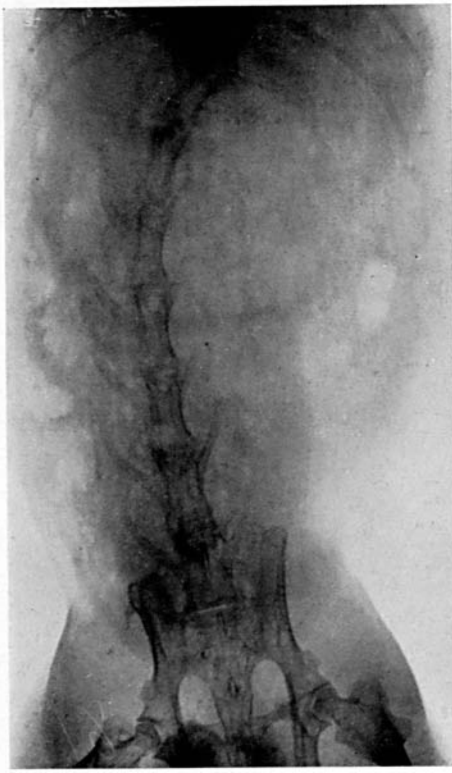


Fig. 4 a.

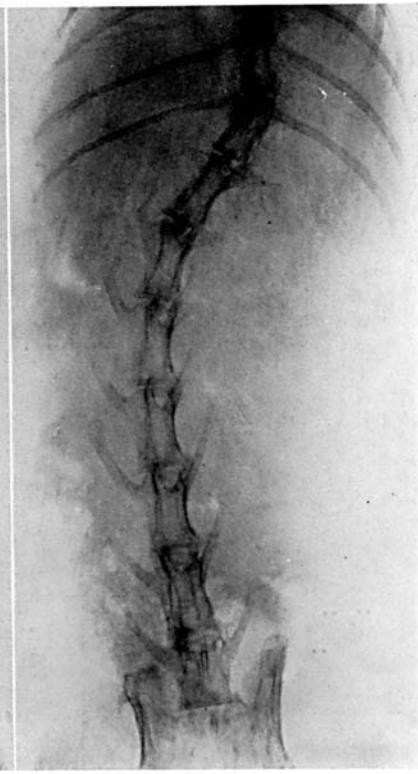


Fig. 4 b.

Fig. 4 a.

Case no. 13. Roentgenogram of the spine taken 337 days after the insertion of the rubber band. A moderate scoliosis still exists.

Fig. 4 b.

Same case. Roentgenogram taken immediately after the second operation—350 days after the first—when the rubber band was found *in situ* and was taken away.

Histological sections of the capsule and the surrounding soft tissues were performed in all cases but one (no. 1), while sections of the iliac bone were performed in 6 cases (nos. 1, 2, 5, 6, 9 and 13).

The specimens were sectioned in 5 μ thick slices and were stained with hematoxylin-van Gieson and with hematoxylin-eosin.

In the great majority of the cases (nos. 1, 3, 5, 6, 7, 8, 9, 10 and 12) the wall of the channel consisted of a well defined membrane of connective tissue, measuring about 0.1–0.5 mm. in thickness. The membrane and its surroundings showed only a very slight inflammatory

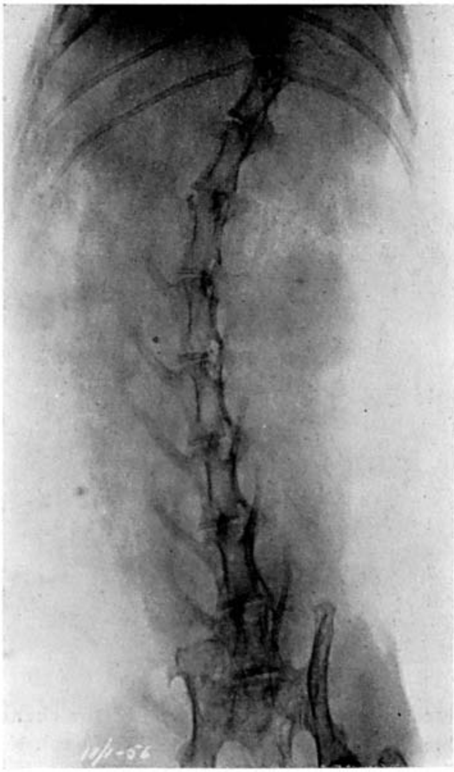


Fig. 4 c.
Same case. 484 days after the insertion of the rubber band and 134 days after it was taken away the scoliosis persists unchanged.

reaction. Only in case no. 6 was there observed a small sequestrum just outside the periosteum of the iliac bone in the immediate neighbourhood of the channel. Here too the inflammatory reaction was very slight.

Concerning the reoperated group (cases nos. 2, 9 and 13 where the rubber band was removed at the second operation) it was impossible to demonstrate any channel in spite of the fact that many specimens from different parts of the operative field were investigated.

In case no. 13 there was a small encapsulated sequestrum outside the periosteum of the iliac bone, at the site of the earlier insertion of the rubber band. No inflammatory reaction was present and the picture strikingly resembled that described in case no. 6. Apart from this sequestrum, there were no structures to be seen which could with cer-

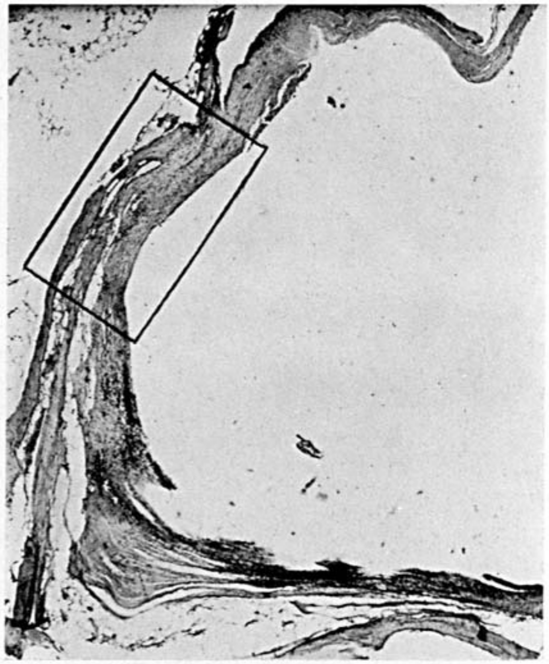


Fig. 5 a.
The connective tissue capsule outlining the walls of the channel is clearly visible, surrounded on two sides by spongious bone (the iliac bone). No inflammatory reaction is present. (× 27).

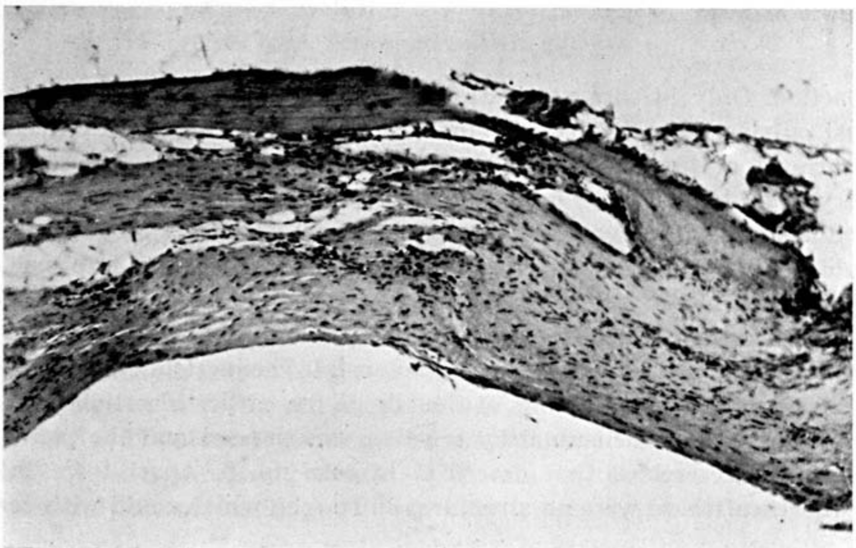


Fig. 5 b.
The inset at high magnification. (× 100).

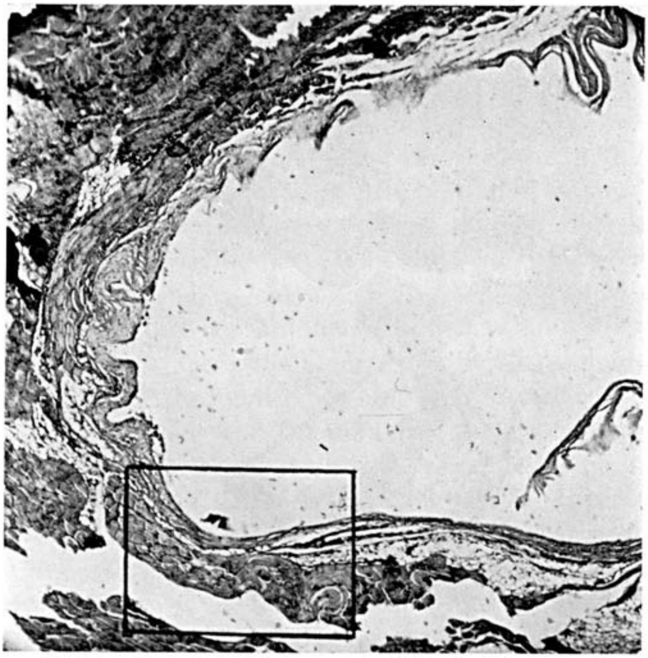


Fig. 6 a.
The capsule outlines the walls of the channel passing, here, through muscle of normal appearance. (× 27).

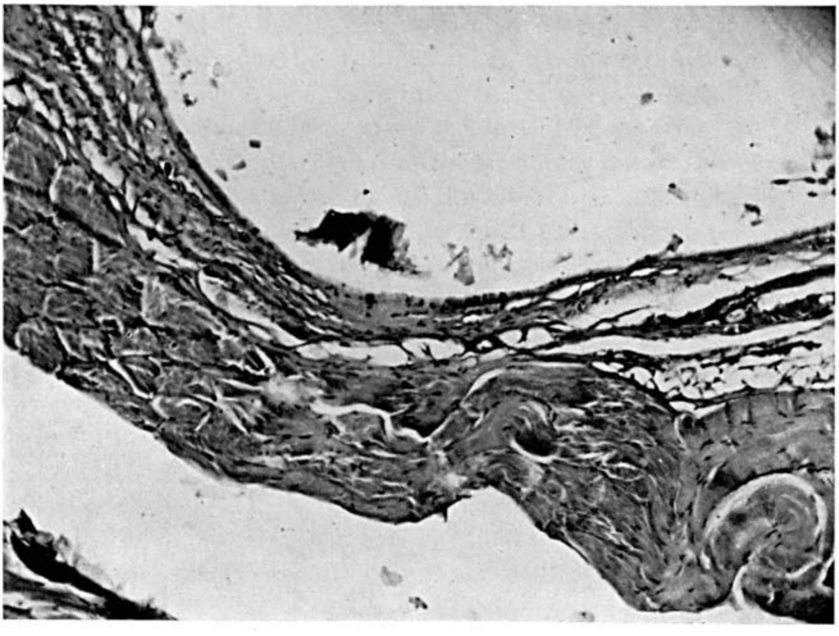


Fig. 6 b.
The inset at high magnification. (× 100).

Fig. 7 a.
The capsule outlining the channel is surrounded by connective tissue and fat with no pathological reaction. (× 27).

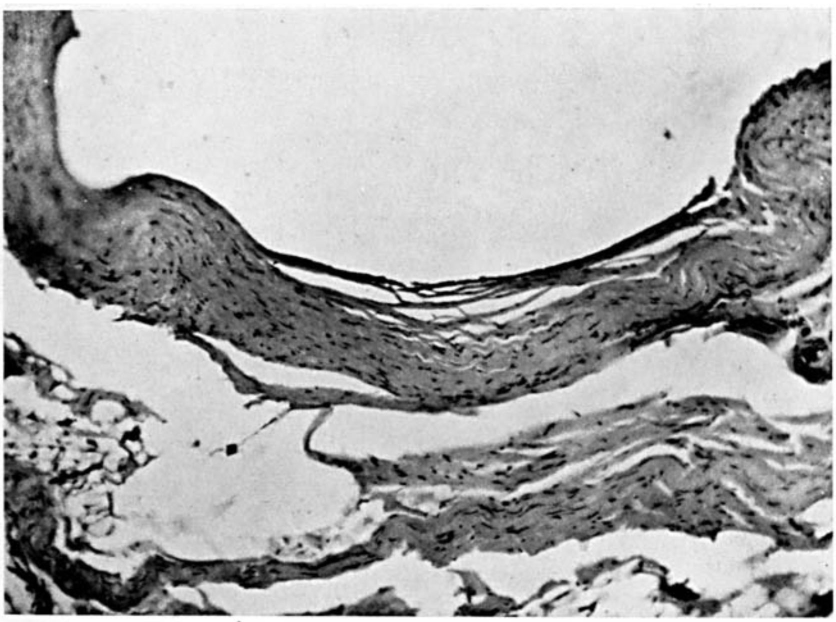


Fig. 7 b.
The inset at high magnification. (× 100).

tainty be identified as belonging to the previous channel and there was no inflammatory reaction (figs. 5, 6, 7).

Testing of the rubber. Mechanical tests of the rubber were performed as follows:

(a) *The internal resistance of the rubber* per unit of the sectioned area, which opposes the deforming action of the outside force (= stress) was examined by means of loading tests. Rubber samples of the quality "695 transparent", treated in different ways, were stamped out with a specially shaped cutting tool and were loaded until rupture. The results of this test are demonstrated in table II.

It becomes obvious from the figures of the above table that the internal resistance of the rubber per unit area (stress), diminishes to about 50 per cent in one year. On the other hand, no remarkable differences are observed between the sample retained in the body of the animal for one year and that which during the same period of time was kept under normal conditions. In other words, rubber is not influenced in any special way by the living tissues but it undergoes a certain deformation whether it is kept under normal conditions or is inserted in the body.

(b) *The deformation and the condition of the rubber* were tested in a special apparatus, where successive tensions and relaxations were performed on 20-mm-wide rubber sheets of different thicknesses. In some cases the rubber sheets were attached to the apparatus completely relaxed while in other cases a tension of up to 70 per cent was applied. Two linear marks, 10 mm. apart, made on the surface of the rubber sheets to be tested, facilitated the reading of the deformation (elongation) of the samples after the test. The deformation, i.e. the increasing of the distance between the two linear marks, was expressed as a percentage. The condition of the rubber, i.e. the appearance of fissures on the surface of the rubber until rupture, was expressed by numerals from 0 up to 10. Thus 0–1 indicates the appearance of very fine superficial fissures, 2–5 the presence of deeper fissures, 6–9 partial rupture and 10 total rupture of the rubber sheet.

The apparatus in the present tests was moved with a speed of 350 movements (tension-relaxations)/min., and at a room temperature of 37–40° C. The results of this test are shown in the table III.

The conclusions drawn from the above table are that rubber is rather tolerant when it undergoes successive tensions and relaxations. In both cases in which a rupture occurred this was evidently due primarily to mechanical conditions arising from the apparatus itself, for

TABLE III

Total no. of tension relaxations	2*		2*		2*		4*		4*		5*		5*	
	0 %**		50 %**		70 %**		0 %**		50 %**		0 %**		50 %**	
	D.	C.	D.	C.	D.	C.	D.	C.	D.	C.	D.	C.	D.	C.
0		0		0		0		0		0		0		0
3,000		0		0		0								
15,000		0		0		0								
24,000		0		0		0								
48,000		0		0		0								
93,000		0		0		0								
100,000								0		0		0		0
150,000		0		0		0								
205,000		0		0		0								
215,000	3	0	8	0		0								
268,000						0								
280,000								0		0		0		0
308,000						0–1								
310,000								0		0		0		0
358,000						2–5								
360,000								0		0		0	1	10
430,000						10								
450,000								0		0		0		
500,000							1	0	1	0	1	0		

D = deformation per cent. C = condition of the rubber.

* Thickness in m.m.

** Applied initial tension.

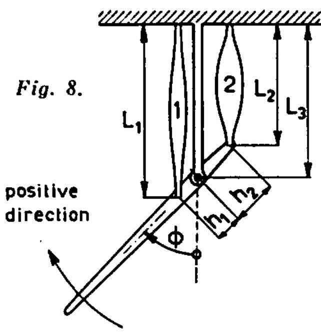
the rupture of the tested rubber samples occurred at the site of fixation, where the rubber was tightly pressed between two metal rods. On the other hand no noteworthy changes in the condition of the rubber occurred after 215,000 to 500,000 tension-relaxations, whether the rubber sheet was under tension or not. As to the deformation, it seems that the thicker the rubber band is, the greater is its "stress". Rubber sheets 4–5 mm. thick showed only a minimal elongation after 500,000 tension-relaxations in the apparatus, corresponding to 24 hours work with a speed of 350 double movements/min.

MECHANICS OF METAL SPRINGS

It has been showed in the preceding part of this work that rubber, when inserted in the body is tolerated by the living animal tissues with practically no pathological tissue reactions. It has also been demonstrated that even rubbers of high quality undergo essential changes with time, by losing a considerable part of their "stress", both when they are inserted in the body and when they are stored outside it under normal conditions, and it is therefore obvious that a strengthening of the rubber is necessary if it is to be used successfully to replace muscle function *in vivo.* Metal springs seem to have right properties for such an application. A survey on the special problems concerning metal springs from a technical viewpoint was found necessary to complete the present investigation.

Only a special case, with special assumptions will be discussed, but the general problem may be treated in similar manner. The special case is a schematic joint controlled by two muscles, no. 1 and no. 2, where no. 2 will be replaced by a spring. (See figs. 8 and 9).

Fig. 8.



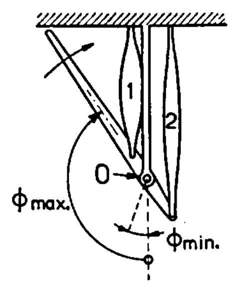


Fig. 9.

Definitions:

Φ = position coordinate
L = total length of the muscle = total space for a spring
h = muscle lever
P = muscle force
P_s = spring force
M = moment about point 0 due to muscle forces
M_s = moment about point 0 due to muscle- and spring-forces
M_{pos} = pos. moment when P_1 = max. and $P_2 = 0$
M_{neg} = pos. moment when $P_1 = 0$ and P_2 = max.

Assumptions: Assume (a) that the muscles can only perform external work by contracting; that means that only muscle no. 1 is strained, while muscle no. 2 is relaxed when producing a positive moment, (b) that at any position Φ between Φ_{min} and Φ_{max} the muscle can perform any muscle force between O and P_{max} and that P_{max} is independent of Φ. (See fig. 10).

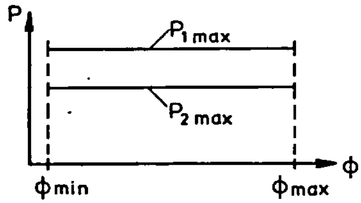


Fig. 10.
Assumed muscle-forces.

If the levers h_1 and h_2 are constants and $h_1 \cdot P_{1max} > h_2 \cdot P_{2max}$ we get the range of work shown in fig. 11.

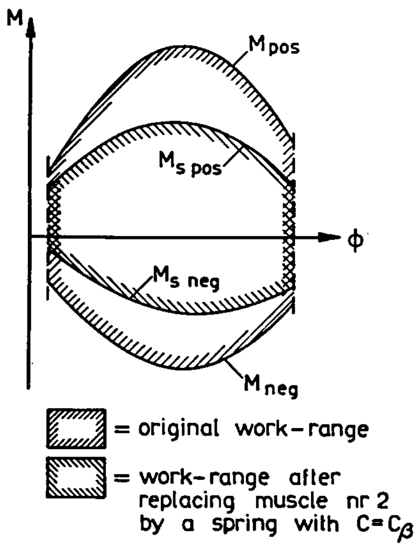


Fig. 11.
Work-ranges.

Suppose that muscle no. 2 is replaced by a spring (add index "s" to symbols for force and moment). For a helical spring made of round wire the force is a linear function of the spring-length with a spring constant $\frac{d\,P_{s2}}{d\,L_2} = C$.

If the lever h_2 (fig. 8) is a constant, and the spring-force P_{S2} is given, the value P_0 (by pre-stressing the spring) at the position Φ_0, the spring-force P_{S2} will vary with Φ as shown in fig. 12, where curves are shown for different values of C.

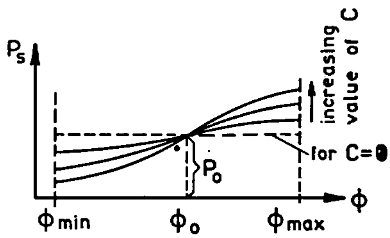


Fig. 12.
Spring-force for different values of C, but for the same value of P_0.

What properties of the spring should be prescribed? In order to get the full possibility of movement between the limits Φ_{min} and Φ_{max} it is necessary that $P_{s2min} > O$ and $P_{s2max} < \frac{h_1}{h_2} \cdot P_{1max}$. The problem is now to choose the magnitudes of P_0 and C in order to get the best range of work. The ideal would be if the relation between max. moment-performance in positive and negative direction respectively for any values of Φ were unaffected by the replacement of muscle no. 2 or if

$$\frac{M_{pos}}{M_{neg}} = \frac{M_{spos}}{M_{sneg}} \tag{1}$$

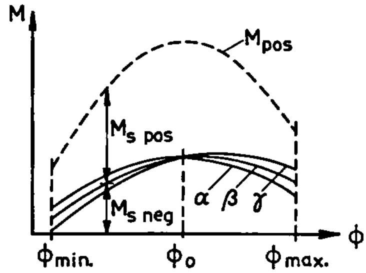
With our present assumptions this is possible only if $C = O$. But C is always $> O$. Thus the spring-constant C should be chosen as small as possible. It is possible to satisfy equation (1) only for one value of Φ; preferably for $\Phi = \Phi_0$, which gives

$$\left(\frac{M_{spos}}{M_{sneg}}\right)_{\Phi_0} = \frac{\frac{h_1}{h_2} \cdot P_{1max} - P_0}{P_0} = \frac{\frac{h_1}{h_2} \cdot P_{1max}}{P_{2max}} = \left(\frac{M_{pos}}{M_{neg}}\right)_{\Phi} \tag{2}$$

Moment-performance and work-range when muscle no. 2 is replaced by a spring with P_0 calculated from equation (2) are visualized in figs. 13 and 11.

Thus the max. performance is reduced to about half the original. Another disadvantage is that the remaining muscle has to be stretched 40–60 per cent for a simple movement without performing any external work if the spring is adapted to give the largest range of work possible.

Dimensioning of the spring. After settling magnitudes of P_0 and C in the manner sketched above it only remains to dimension the spring.



$\alpha = M_{s\,neg}$ for $C = 0$

$\beta =$ —»— $C = C_\beta > 0$

$\gamma =$ —»— $C = C_\gamma > C_\beta > 0$

Fig. 13.
Moment-performance for different values of C.

Instead of settling P_0 and C it may be more practical to prescribe the spring-force at two different positions (Φ), e.g. P_{s2min} for position Φ_{min} and P_{s2max} for position Φ_{max}.

Given data:

For Φ min: Spring-force $= P_{s2min}$; Space for spring length $= L_{2min}$.
Φ max: Spring-force $= P_{s2max}$; Space for spring length $= L_{2max}$.

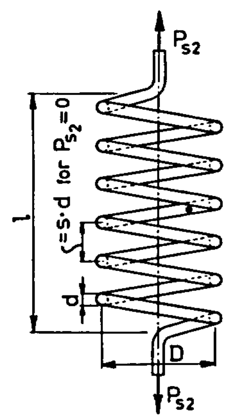


Fig. 14.

Definitions:

G = bulk modulus of the material
τ = maximum torsion stress of the material
τ_p = maximum permissible torsion stress with respect to fatigue

n = number of effective turns
l = effective length of the spring
s = dimensionless factor of distance between two turns when $P_{S2} = 0$
k = a correction factor depending on the relation $\frac{d}{D}$ (given in most engineering handbooks).

From the strength of materials:

$$\begin{cases} C = \frac{G}{8_n} \cdot \frac{d^4}{D^3} = \frac{P_{s2max} - P_{s2min}}{L_{2max} - L_{2min}} \\ \tau = K \cdot \frac{8D}{\pi d^3} \cdot P_{s2max} \leq \tau_p \end{cases}$$

$$\text{or} \begin{cases} \frac{Kd}{n D^2} = \frac{\tau}{G} \cdot \frac{\pi}{L_{2max} - L_{2min}} \cdot \left(1 - \frac{P_{s2min}}{P_{s2max}}\right) \text{ where } \tau \leq \tau_p \\ \text{and } l_{max} = nd \cdot \left[s + \frac{\tau}{G} \cdot \underbrace{\frac{\pi}{K}\left(\frac{D}{d}\right)^2\right] < L_{max}}_{\text{enough to give space for mountings.}} \end{cases}$$

The values of n,d and D must satisfy the equations above.
If several springs are mounted parallel the spring forces and spring constants of each spring will be added.

DISCUSSION

As has been mentioned elsewhere in this article, some experimental attempts, of a more or less empirical character, to replace muscle function by elastic endoprosthesis have been made earlier.

A. Lambotte was the first to try to replace paralysed muscles by rubber internal prosthesis. In 1932 he operated on four cases of residual paralysis in children affected by poliomyelitis. He replaced the paralysed muscle-groups of the extremities by rubber band. In an account of the experience gained from his first cases Lambotte (1947) stated that a very satisfactory functional result was obtained immediately after the operation in all the cases, but within a few weeks the rubber lost its elasticity and thus the late results were negative. The author considered, however, that the application of metal springs met the requirements for the late results desired, provided they were not stretched more than 30 per cent of their lengths.

Von Voelker (1934), after earlier unsuccessful attempts to replace the paralysed sphincters in the anus and bladder by rubber rings, obtained encouraging results by replacing the paralysed peroneal muscle-groups in five patients with stainless-steel springs.

Klages (1934), reported the observations made on 19 dogs as well as observations on von Voelker's material. By replacing the peroneal muscle-groups in the dogs with stainless-steel springs he tried to follow up the histological changes of the tissues. He found that the springs were enclosed in a capsule of connective tissue which in the older cases (297 days old) became hardened and of a tendinous consistency. As to whether the function of the springs diminished with time, because of the production of hard connective tissue, as is often found in embodied movable foreign bodies in general, he observed that the springs he used in his own experiments kept their functional condition almost unimpaired. In one case the spring applied in the dog functioned with undiminished strength after 1½ years.

Recently Borellini (1952), has published the results obtained by experiments on two dogs in which he replaced the quadriceps and triceps muscles by stainless-steel-spring internal prostheses. The author got very satisfactory results after an observation period up to six months and he consequently operated with the same technique on two patients with paralytic deformities of the foot. Here, too, satisfactory functional results could be observed after 4 and 5 months respectively.

The historical data given above and the fact that the application of the method, in spite of its great interest for orthopaedic and reconstructive surgery, has not gained wider recognition, show, in the author's opinion, that the problem still remains unsolved.

The experimental results set out in the present paper support the view that the successful application of elastic internal prostheses in patients is possible.

The combination of rubber and metal-springs has the advantage that tissue reactions are limited to a minimum. Furthermore, such prostheses are more supple and by enclosing the springs in rubber one avoids the filling of the central cavity of the spring by hard connective tissue (Klages 1934) which probably would affect the functioning of the springs. On the other hand, steel springs give practically unlimited possibilities as to the strength and the time of function in such endoprostheses.

With suitable technical help special devices can be constructed for the successful application of the method in patients.

The field of indications of such operations is large. Apart from the many varieties of paralysis arising from poliomyelitis, traumatic nerve injuries, scoliosis, spastic paralysis as well as other deformities can be alleviated.

SUMMARY

An experimental investigation was undertaken in order to study the possibilities of replacing muscular function by internal elastic devices.

Thirteen rabbits were operated on and a stretched rubber band was mounted in their vertebral skeleton between the crista ilica and one of the lower thoracic vertebrae. A severe to moderate scoliosis resulted, which in three cases was followed up to 608 days. The scoliosis was of a permanent character, i.e. it remained more or less unchanged 116 or more days after the rubber was removed.

No pathological reactions of the tissues were observed after one to one and a half years. In all the cases the rubber was isolated in a very thin capsule of connective tissue, lubricated by a small quantity of a highly viscous fluid.

The elasticity of rubber samples either remaining in the body up to one and a half years or stored outside it at room temperature deteriorated approximately 50 per cent in both cases.

A study of the mechanics of the steel springs showed that stainless-steel springs of a high quality (18–8) retain under optimum conditions their elasticity practically without limitations of time and action.

It is the author's opinion that elastic internal devices constructed from steel springs encased in rubber can be successfully used as substitutes for paralysed muscles.

RESUME

Une enquête expérimentale a été entreprise afin d'étudier la possibilité de remplacer la fonction musculaire par un procédé élastique interne.

13 lapins ont été opérés et un ruban de caoutchouc tendu a été monté sur la colonne vertébrale entre l'os iliaque et l'une des vertèbres dorsales inférieures.

Une scoliose, variant d'un degré grave à un degré modéré, en est résulté. Celle-ci a été suivie dans trois cas pendant une période allant

jusqu'a 608 jours. La scoliose avait un caractère permanent, en particulier elle persista plus ou moins inchangée pendant 116 jours ou plus après l'enlèvement du ruban de caoutchouc.

Aucune réaction pathologique des tissus n'a été observée après un an ou un an et demi. Dans tous les cas, le caoutchouc était isolé par une très mince capsule de tissu conjonctif, lubrifié par une toute petite quantité de liquide d'une haute viscosité.

L'élasticité des échantillons de caoutchouc, après être resté dans le corps pendant une période allant jusqu'à un an et demi ou placé en dehors, à la température de la chambre, se détériore d'environ 50 % dans les deux cas.

Une étude du mécanisme des ressorts en acier de haute qualité (18 –8) montre que ceux-ci, dans des conditions optimales, conservent leur élasticité pratiquement sans limite de temps et d'action.

L'auteur est d'avis qu'un procédé élastique interne consistant en un ressort en acier entouré de caoutchouc pourrait être utilisé avec succès pour remplacer des muscles paralysées.

ZUSAMMENFASSUNG

Experimentelle Untersuchungen wurden vorgenommen, um die Möglichkeiten der Erstattung von Muskelfunktion durch innere elastische Vorrichtungen herauszufinden.

Dreizehn Kaninchen wurden operiert und ein angespanntes Gummiband wurde in ihrem Wirbelskelett zwischen der Crista iliaca und einem der unteren Brustwirbel angebracht. Das Ergebnis war eine moderate bis schwere Skoliose, die in drei Fällen bis zu 608 Tagen beobachtet werden konnte. Die Skoliose war beständig, d.h. sie verblieb mehr oder minder unverändert 116 Tage, ja selbst länger, nach der Entfernung des Gummibandes.

Pathologische Veränderungen des umgebenden Gewebes wurden nach ein bis einuneinhalb Jahren nicht beobachtet. In allen Fällen war der Gummi von einer sehr dünnen Kapsel von Bindegewebe umgeben, die von einer kleinen Menge hochvisköser Flüssigkeit gleitfähig erhalten wurde.

Die Elastizitet von Gummiproben, die entweder ein bis eineinhalb Jahre im Körper zurückgelassen worden waren oder aber ausserhalb desselben bei Zimmertemperatur aufbewahrt worden waren, verschlechterte sich in beiden Fällen um ungefähr 50 %.

Eine Untersuchung der mechanischen Eigenschaften von Stahl-

federn hoher Qualitet (18–8), zeigte, dass sie unter den besten bedingungen ihre Elastizitet für eine unbegrenzte Zeit beibehalten.

Der Verfasser ist der Meinung, dass innere elastische Vorrichtungen, die aus gummiüberzogenen Stahlfedern konstruiert sind, erfolgreich als Ersatz von gelähmten Muskeln verwendet werden können.

ACKNOWLEDGMENTS

The author is very grateful to Dr. L. B. Schnürer, Uppsala, for help with the histological part of this work and to Mr. L. E. Jarfall, Stockholm, who contributed the section on the mechanics of the steel springs. The rubber samples used throughout were placed at our disposal by the Ulvsunda Gummifabriks AB, Stockholm, and all rubber tests were performed in the laboratories of that company under the kind supervision of its chief engineer, Mr. F. Bergwall, assisted by Mr. G. Törnquist.

The present investigation was supported by a research grant from the insurance company "Folksam", Stockholm.

LITERATURE

1. *Borellini, A.:* Sostituzione di muscoli con molle in acciaio. La Clinica Ortopedica, Vol. IV, 2, 91–98, 1952.
2. E possibile la sostituzione di muscoli con molle in acciaio nell uomo? Rivista Romagna Medica, Vol. IV, 4, 1–11, 1952.
3. *Klages:* Untersuchung über die Einheilung und Funktion der Voelkerschen Spiralen. Archiv für Klinische Chirurgie, *180*, 140–142, 1934.
4. *Lambotte, A.:* Note sur l'emploi de la prothèse élastique perdue dans les paralysies musculaires. Bull. et Mém. de la Soc. de Chir., *18*, 181–193, 1932.
5. – La prothèse élastique perdue dans les paralysies. Bul. de l'Acad. Roy. de Méd. de Belgique, VII serie, *12*, 384–398, 1947.
6. *v. Voelker:* Erfahrungen mit der Einheilung von Stahlfedern als Muskelersatz. Archiv für Klinische Chirurgie, *180*, 347–348, 1934.