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DEVELOPMENT OF THE TECHNIQUES OF OCULAR MUSCLE SURGERY

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Introduction

Viewing the surgical procedures purely from a physico-mechanical standpoint, as for example ELSCHNIG (1908) did, the principles can be demonstrated rather simply. The circumference of a normal eyeball is approximately 75 mm. Displacement of the point of insertion of a horizontal rectus muscle by 1 mm corresponds to an amount of 360/75, i.e. a positional change of the eyeball of about 5 degrees. In a convergent squint of 15 degrees, a displacement of the muscle by 3 mm should, therefore, result in the desired correction. This simple theoretical conception is, however, rarely confirmed in practice.

Considerable variations exist in eyeball diameter, muscle course, and muscle insertion, muscle elasticity, configuration of the bony orbit, connective tissue apparatus, etc. (OTTO and ZIMMERMANN, 1979). Since we know a fair amount about the mechanical properties of the entire muscle and the elasticity of the orbital tissue, the decrease of the angle of deviation after surgery can be empirically calculated. Analytical examinations of the mechanics of the peripheral elements of the oculomotor apparatus are only beginning (ROBINSON, 1978).

To assess the system of oculomotor control is much more complicated since this is a dynamic, cerebrally directed feedback system.

To choose the correct amount of muscle displacement for a squint operation, all these factors have to be taken into consideration. However, since prognosis of the effect of the operation on the central oculomotor control system is only approximate, the results — even after identical ocular muscle operations — scatter considerably. Among all ophthalmological operations, including those with high technical difficulties, strabismus operations have the highest degree of uncertainty (FRÖHLICH, 1900). More precise prognosis and procedures are therefore strived for. In no other field of invasive ophthalmology, exists there such a plethora of procedures as in operative strabismus therapy. Nevertheless, almost all types of strabismus operations available today can be reduced to two main principles:

— operations for limiting the action of a muscle and
— operations for enhancing the action of a muscle.

Operations limiting muscle effectivity

Myotomy

To treat strabismus, STROMEYER (1838) proposed surgical cutting of the muscle with a cataract knife or a pair of scissors after inserting a probe below the muscle. Experimenting on autopsy material he severed the muscle 6 to 8 mmm behind its scleral insertion (FLICK, 1928). DIEFFENBACH (1839) then reported the first squint operation in a living patient. He stated that he cut the muscle close to the eyeball. In his major work (DIEFFENBACH, 1842), however, he wrote: *"Die Durchschneidung des Muskelbauchs geschieht, indem ein Scherenblatt unter demselben (Muskel) durchgeführt wird, drei bis vier Linien von der Sehne entfernt"*[1]. *Today it is not possible to ascertain at which exact site Dieffenbach usually cut the muscle. In the first operations, this probably varied from surgeon to surgeon and from case to case. From the descriptions it can be gathered that a larger or smaller remnant of tendon or tendon and muscle remained attached to the scleral insertion after the cut. Since myotomy is more traumatizing and technically more difficult than tenotomy and also more prone to complications, BÖHM (1845) suggested to replace the myotomy by a tenotomy.*

Tenotomy

Although tenotomy, i.e. the cutting of the tendon of the ocular muscle, was mainly practiced in the beginning (ARLT, 1874), it lost its significance due to

[1] "Severing of the muscle is achieved by inserting one blade of the scissors below it (i.e. the muscle), 3 – 4 lines (i.e. 1/3 inch) anway from the tendon" (author's translation).

the increasing number of surgical failures from 1843 onwards. Then VON GRAEFE (1857) succeeded in re-establishing its significance:

> "The common squint operation consists of a recession of the muscle tendon, without altering the muscle length".

He gave a rather detailed report on the technique of the operation. After opening the conjunctiva, he dissected the subconjunctival fascia, passed a muscle hook under the muscle, pulled the tendon upwards and cut it at its scleral insertion with a pair of scissors (fig. 1).

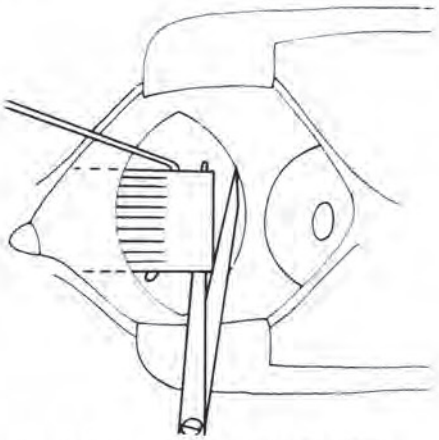


Fig. 1: Tenotomy after VON GRAEFE

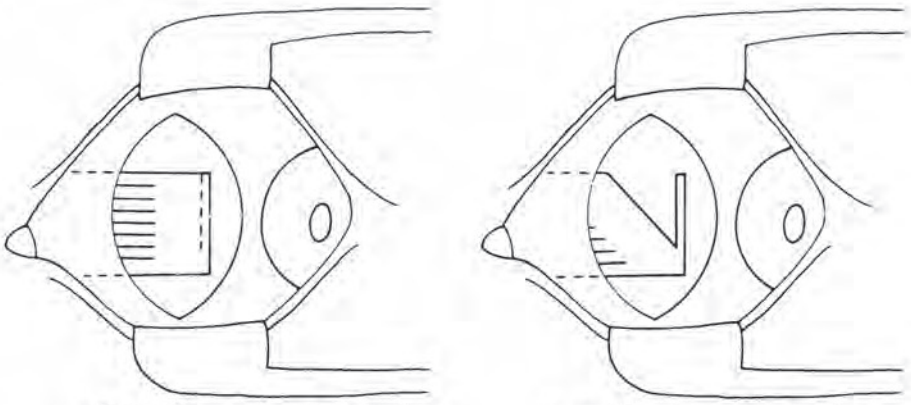
CRITCHETT (1855) performed a conjunctival tenotomy. Soon numerous modifications of the operation existed, the conjunctiva was opened only on one side of the muscle tendon, or on both; different muscle hooks were used; finer scissors and many more instruments designed. HASNER (1873) grasped the conjunctiva and the muscle tendon with a forceps and severed the muscle with one cut with a pair of scissors.

Since the effects of myotomy and tenotomy were not predictable, DIEFFENBACH in 1842 advocated controlling the effect with sutures. He tied the sutures around the tendon at its sceral insertion, pulled them towards the bridge of the nose and fixed them there with a plaster. The eyeball was thus held in an adducted position for several days. DIEFFENBACH believed that, in the meantime, the severed medial rectus re-attached itself to the sclera, its position being determined by the suture-fixation. Thus he hoped to prevent an uncontrollable retraction of the muscle. VON GRAEFE (1857), on the other hand, believed that overcorrections were prevented by a careful operating technique and appropriate cutting of muscle sheaths and check ligaments.

Partial tenotomy

With a complete detachment of the muscle, the effect of the operation was hardly controllable, despite fixation of the eye by means of sutures or preservation of the fascial tissue. For this reason it was attempted to make the operation more predictable and reliable by cutting the tendon only partially. The first suggestions came from VON GRAEFE (1857) who cut the edge of the tendon perpendicularly to the line of action of the muscle (fig. 2) or, which is certainly more satisfactory, cut the central part of the tendon, so that the cut portion was displaced downwards (fig. 3). This resulted in a certain weakening of the muscle, as well as in a limited lengthening of the tendon.

Fig. 2: Partial tenotomy according to VON GRAEFE (1857);



a: before the operation (line of incision = broken line)

b: partial recession of the muscle after the operation

As the effect of these operation was too limited, VON GRAEFE soon abandoned the method. By 1880, however, partial tenotomy was revived by ABADIE, who made a large incision at the upper and lower margins of the tendon so that only a narrow central piece of tendon remained. Especially STEVENS (1887) advocated and propagated partial tenotomy. A number of variations, intending to more or less weaken and lengthen the muscles, were published in the years of follow (fig. 4).

VERHOEFF (1903) combined VON GRAEFE's and ABADIE's methods, thus obtaining a more pronounced lengthening of the muscle. Until today, ophthalmic surgeons have time and again revived the principle of tenotomy and attempted to determine the appropriate amount of muscle lenghtening (KROCZEK et. al., 1970).

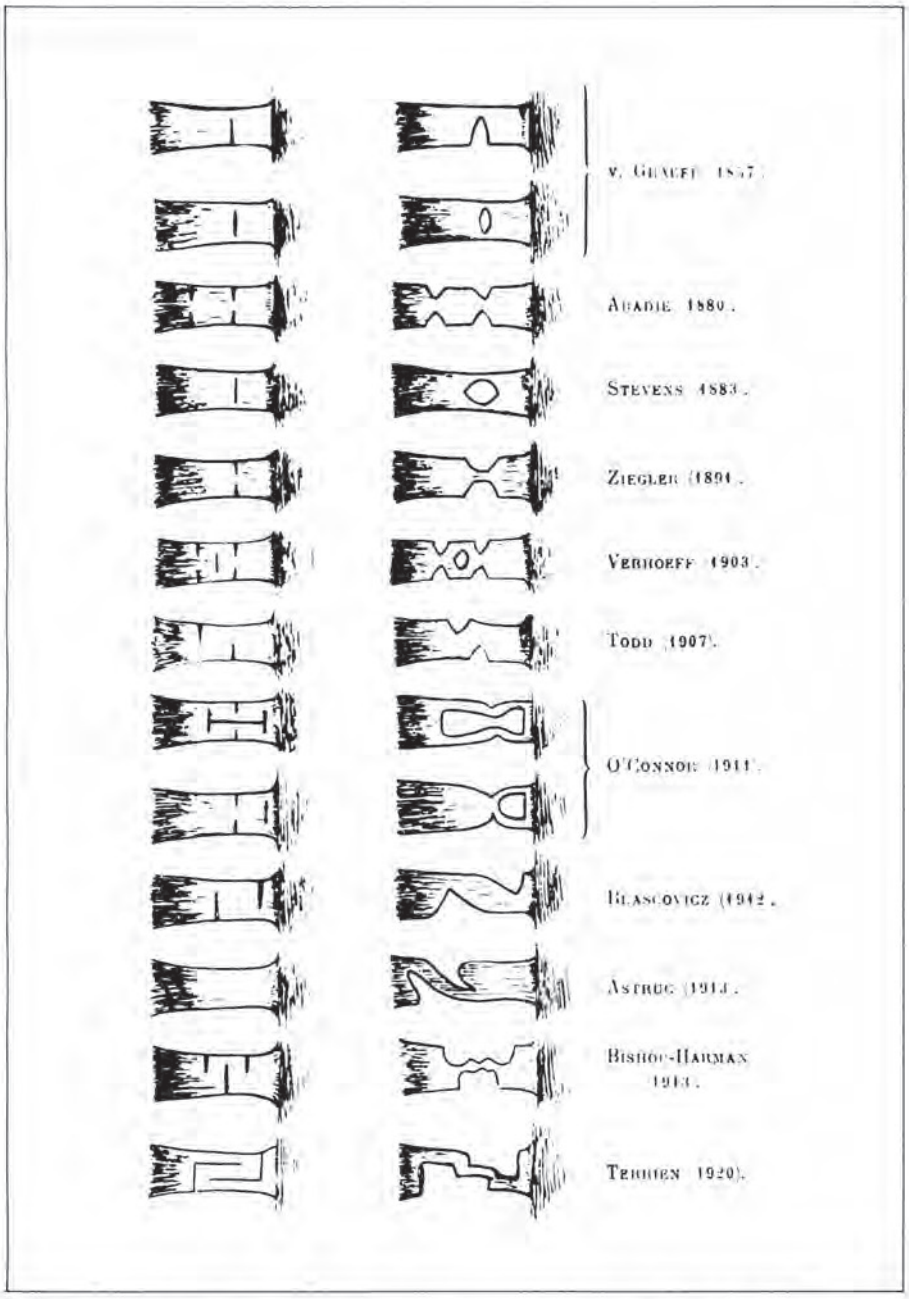


Fig. 3: Different methods of partial tenotomy (reproduced from VAN DER HOEVE, 1922)

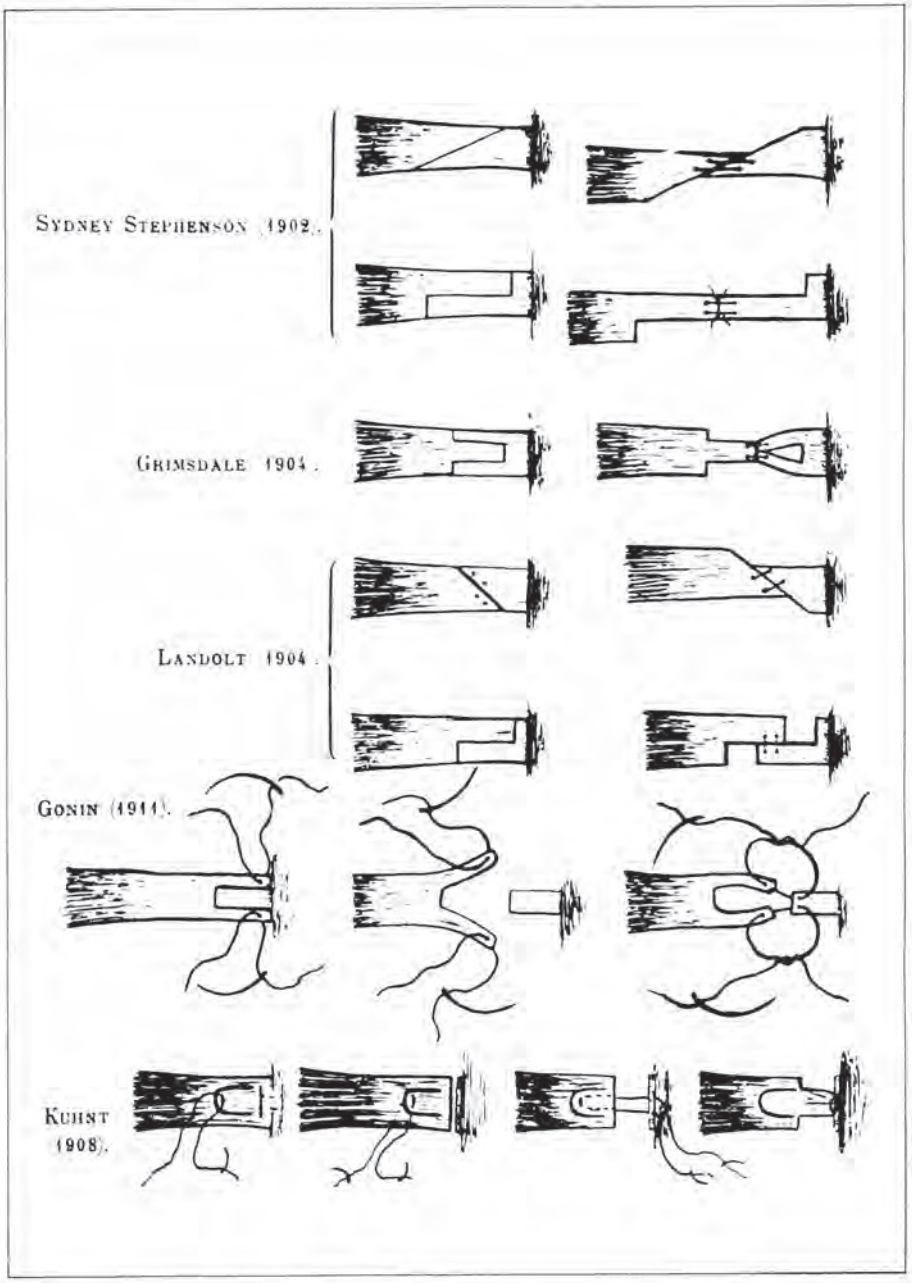


Fig. 4:
Methods of lengthening ocular muscle tendons (reproduced from VAN DER HOEVE, 1922)

Tendon lengthening

Tenotomy is of little effect and also unpredictable due to scar formation. For this reason, a more predictable procedure for muscle lengthening was strived for. The decisive idea came from STEPHENSON (1902). He completely severed the tendon by an oblique or step-like incision and then re-sutured both ends of the severed tendon together. In this manner he achieved a measurable amount of tendon lengthening, retaining the arc of contact. After publication of these methods, numerous descriptions of other, partly similar, procedures followed. Presumably, GRIMSDALE (1904) and LANDOLT (1905) developed their methods without knowledge of STEPHENSON's procedures. Tendon lengthening procedures after GONIN (1911) are practiced up to this day, after having been revived and modified by HOLLWICH (1961). A summary of all the procedures known at his time was compiled bei VAN DER HOEVE in 1922 (fig. 5).

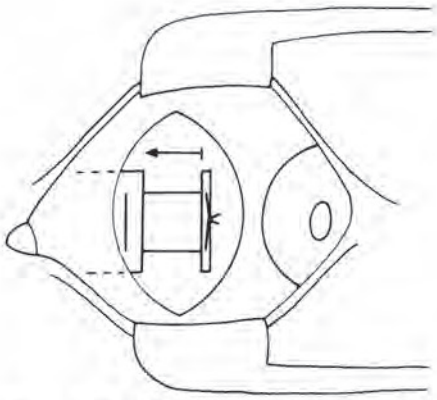


Fig. 5: Graded tenotomy: The severed muscle is held by fixation sutures and is thus prevented from retracting

Somewhat different from these classical procedures, PIERSE (1959) attained tendon lengthening by exposing a portion of the sclera in front of the muscle insertion. CHAVASSE (1934) attempted to obtain a lengthening effect by electro-coagulating a circumscribed muscle portion, while HUYSMANNS (1956) weakened the muscle by injecting hyaluronidase. These methods were not generally accepted.

Also of little significance were the so-called graded tenotomies (fig. 6). This was probably PRINCE's (1885, 1887) idea; he tried to prevent further retraction of the muscle by placing sutures through the severed tendon and anchoring the sutures in the sclera at the insertion. Depending on the post-

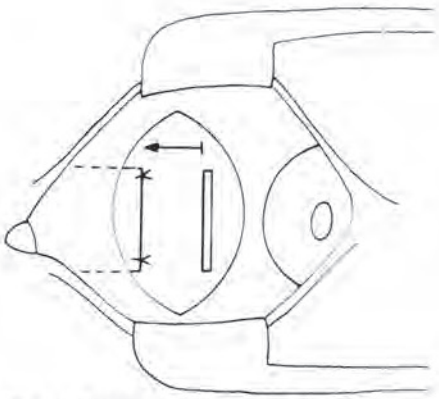


Fig. 6: Recession: The detached and recessed muscle is fixed to the sclera by means of sutures

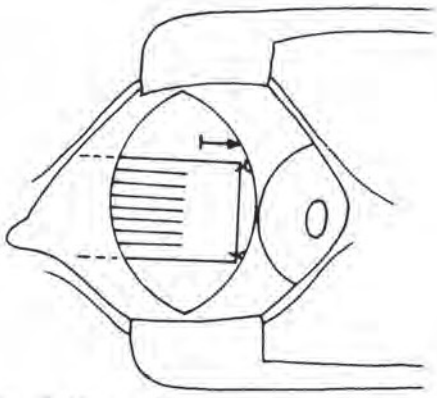


Fig. 7: Muscle advancement according to CRITCHETT (1855); base of arrow indicates old site of insertion

operative effect, the sutures could be either tightened, thus diminishing the recession, or loosened, thus increasing the recession; the sutures were then tied.

In Germany, it was KUHNT (1912) who propagated the graded tenotomies. The method was not very successful, as the tendon can, within the first post-operative hours or days, be pushed up, down or even forewards, the new position of insertion therefore being unpredictable. After the introduction of the recession procedures, the graded tenotomy lost its significance. It was, however, not altogether forgotten (HASS, 1965).

Recession

VON PFLUGK (1905) was presumably the first to fix the detached and recessed muscle by means of sutures to the sclera (fig. 7). Fixation of the muscles to the sclera by means of sutures had been practiced earlier (CRITCHETT, 1855), but only in cases of advancements.

After the first development of ocular muscle surgery, it took a long time until metrically reliable recession methods became significant. This was primarily due to the complicated and time-consuming surgical technique, which, contrary to other operations of those days, required anesthesia. Secondly , it was due to the danger of scleral perforation when placing sutures through the physiologically thin scleral portion behind the rectus insertions.

While VON PFLUGK still used coarse silk sutures, KUHNT (1912) and FORSMARK (1913) used fine catgut sutures to secure the muscle several millimeters behind its original line of insertion. JAMESON (1922, 1925) declared the graded recession an ideal method for weakening the muscle action, as it avoided the uncertain results of tenotomy, made squint surgery safer, provided

a clearer field of operation and also provided suitable conditions for re-operations. BURIAN (1950), O'CONNOR, still in 1935, warned against the risks of the graded recession. In the meantime adjustable sutures following a recess operation on a cooperative patient have made this operation exquisitly quantifiable. The suture is adjusted on the first postoperative day when the muscle has regained its normal strength and when the muscle balance can be measured with the prism-cover test (JAMPOLSKY, 1978).

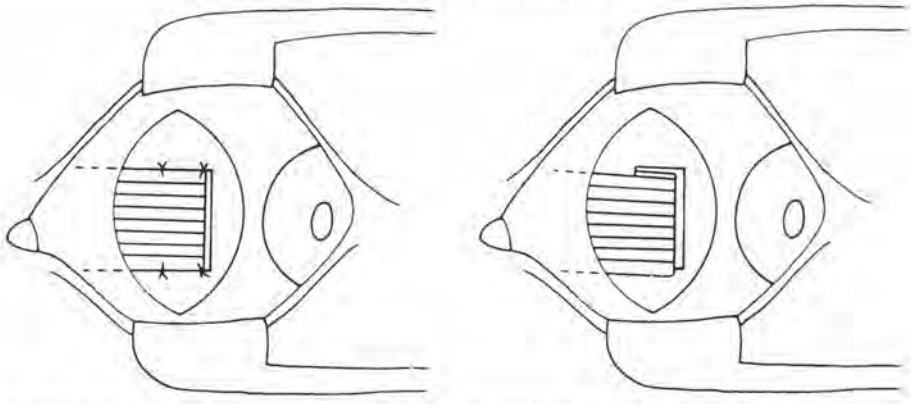
Operations enhancing the action of the muscle

Advancement

STROMEYER's concept of a strabismus operation aimed principally at weakening muscle action. But since these methods also caused many overcorrections, so that an originally convergent strabismus became a large divergent strabismus, attempts to correct such iatrogenic secondary deviations were made.

In 1849, GUÉRIN described an ocular muscle advancement technique and revived DIEFFENBACH's idea of traction sutures. However, he anchored these sutures, in cases of secondary postoperative divergent deviations in the temporal conjunctiva and sclera, anterior to the external rectus insertion and secured them over the nose. Before that, he exposed the retracted and cicatricial internal rectus (result of tenotomy) and allowed the muscle to reattach itself at the original line of insertion (DESMARRES, 1858). GUÉRIN mainly used the traction sutures to correct divergent deviations caused by other surgeons. In a few cases of convergent squints he attempted grading the tenotomy. These methods, however, allowed only rough grading and had unsatisfactory results. Probably for this reason, CRITCHETT (1855) advanced the muscle and secured it by means of sutures to its new line of insertion (fig. 8).

Fig. 8: Tucking of the tendon;



a: tendon fold before placement of sutures, b: situation after placement of sutures

Like GUÉRIN, CRITCHETT employed this method to advance originally tenotomized muscles. VON GRAFE saw the possibility to cure muscle palsies and primary divergent deviations by means of the advancement. He therefore adopted GUÉRIN's methods and later CRITCHETT's. But he soon realized that the effect of an advancement could be enhanced if combined with a weakening operation (tenotomy) of the antagonist. For the first time, the idea of a simultaneous combined strabismus operation (recession-resection) was introduced, which is even today the most widely applied method.

Since advancement and especially placement of sutures is more difficult and complicated than simple tenotomy, it took a relatively long time until this method became accepted and employed.

LANDOLT (1905) asked himself why nobody before (CRITCHETT) had the idea to fix a muscle to the sclera by means of sutures.

Anesthesia was a risk to be taken into consideration:

"The patient undergoing such an (ocular muscle) operation is anesthetized only in cases of muscle advancement or muscle resections" (ELSCHNIG, 1908).

A disadvantage of muscle advancements is that the muscle adheres to the original line of insertion and that the advanced muscle under the conjunctiva is disturbing.

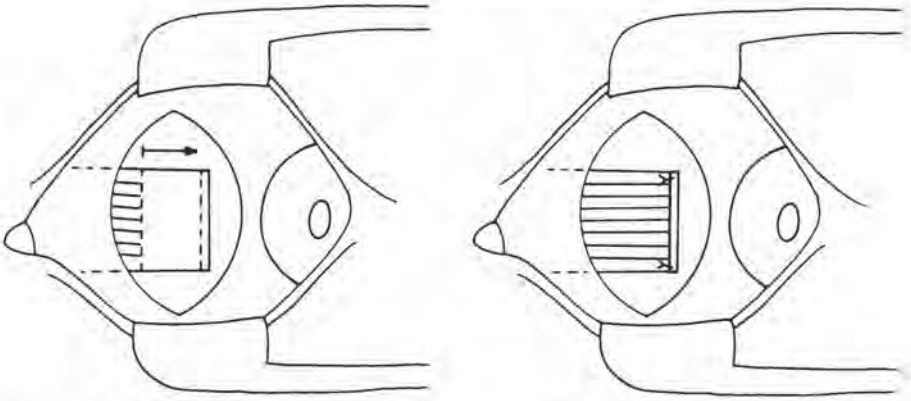
Tucking and folding

The above mentioned disadvantages of the advancement procedures were avoided by retaining the original site of insertion. The first so-called strenghthening operations of this kind were attained by duplication of the tendon. SNELLEN (1870) and NOYES (1874) severed the muscle tendon a few millimeters behind the line of insertion and sutured the free muscle ending underneath the remaining rest of tendon at the original site of insertion.

A type of muscle tucking is the sheath-advancement described by DE WECKER (1873). Conjunctiva, muscle sheath and muscle tendon are folded simultaneously and secured by sutures. An advantage of this method is that the blood vessels supplying the anterior segment are only little affected. Moreover, this method is relatively safe (the muscle cannot retract) and also reversible within the first post-operative days, when the muscle can be unfolded again. Tucking (fig. 9) soon became popular and it is still employed today (KOPER, 1964).

A combination of tucking and resection was performed by SCHWEIGGER (1870, 1894), who tucked the tendon, secured it with sutures and then severed the tuck. Later (1899) he changed over to resections.

Fig. 9: Resection of an ocular muscle;



a: exposure of the tendon before severing (lines of incision = broken lines).

b: resection, advancement of the muscle and sutures

Resection

Foldings, as advocated by SNELLEN (1870) and NOYES (1874), represented in fact a form of resection; they are termed "advancements" although the muscle is not advanced in front of its original line of insertion: "*because a more posterior portion of the muscle is advanced towards the line of insertion*" (VAN DER HOEVE, 1922). In those days, no clear distinction was made between advancement and resection.

In 1876, DRIVER practised a muscle shortening operation, by removing a portion of the muscle or tendon and then securing the muscle at its original line of insertion (fig. 10). In the beginning, solitary resections, instead ot tenotomies of the stronger muscle were employed; then MÜLLER (1893) propagated resection of the weaker antagonist as a complementary procedure to the customary tenotomy. He thus followed VON GRAEFE's idea of a combined procedure. The latter combined the recession with a resection of the antagonist muscle.

Other methods

Other procedures of strengthening muscle action have not gained any importance. Cinching after O'CONNOR (1935, 1955) should, however, be mentioned (fig. 11). The tendon is split into strands, around which a thick suture is wound and then pulled taut. These multiple loops, similar to threads in a weaver's loom, have the effect of shortening the tendon by a sufficiently constant amount (GUZZINATI and SALVI, 1956, WILLIAMS, 1978).

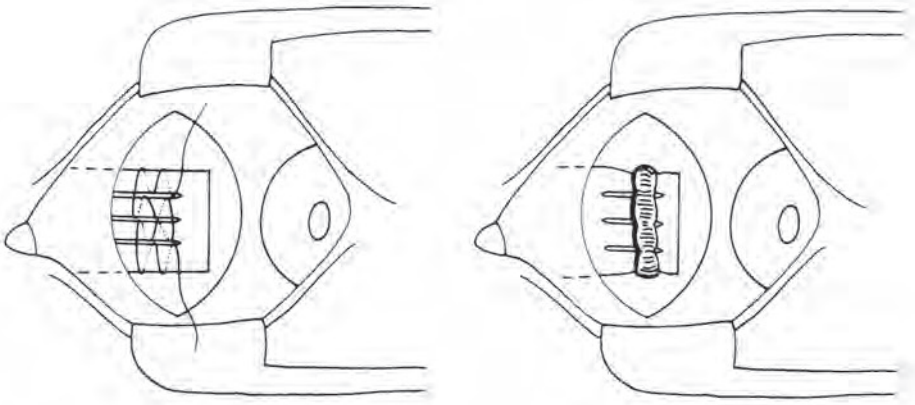


Fig. 10: Cinching according to O'CONNOR (1935, 1955); a: placement of sutures; b: situation after tightening of the sutures

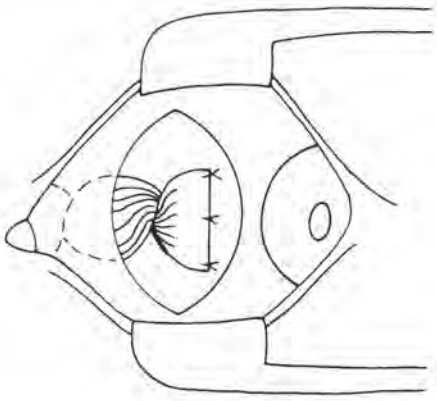


Fig. 11: Screw-form shortening of a muscle according to MALBRAN (1965)

MALBRAN (1965) recommended a screw-form type of shortening; the muscle was disconnected from its insertion, wound once or several times around its longitudinal axis and then fixed to its original line of insertion (fig. 12). This procedure, however, alters the muscle structure. Muscle fibres are destroyed and replaced by connective tissue (STAPLES and JACKSON, 1969).

Muscle transposition

After experimental examinations on rhesus monkeys, HUMMELSHEIM (1907) introduced the method of muscle transposition. The first patient was a 12-year-old girl with congenital VIth Egg nerve palsy. HUMMELSHEIM

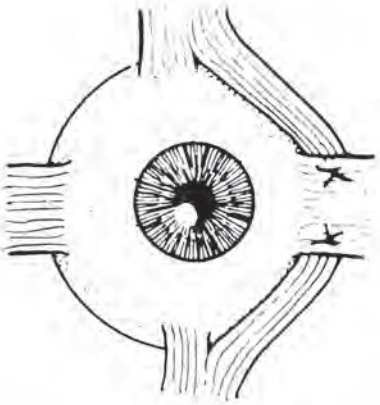


Fig. 12: Ocular muscle transposition of HUMMELSHEIM (from HELVESTON, 1977)

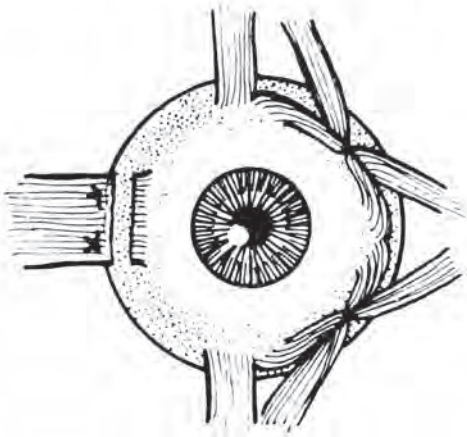


Fig. 13: Operation procedure of JENSEN (From HELVESTON, 1977)

severed the temporal halves of the superior and inferior recti from their insertions, transposed them laterally and secured them to the insertion of the external rectus (fig. 13). The surgical results in the case of this girl, as well as in another patient, were good (HUMMELSHEIM, 1909).

Still today it is unclear, whether the effect of muscle transposition is purely mechanical, as stated by METZ and SCOTT (1970), or whether, the innervation pattern of the transposed muscle is in fact altered, as proven in animal experiments by MARINA (1912) and later by LEINFELDER and BLACK (1941, 1942) and BLATT (1961). In the course of time many variations of HUMMELSHEIM's original method have been described (O'CONNOR, 1935; HELVESTON, 1975; CARLSON and JAMPOLSKY, 1979).

In the usual cases of ocular muscle transposition all four recti of one eye are operated upon, as it is also necessary to recess the antagonist, usually the internal rectus. Since larger blood vessels, supplying the anterior segment of the eye, run within the ocular muscles (resp. the sclera), nutritive damage after such operations has been described.

JENSEN (1964) believes that these complications are prevented by a modification of the muscle transposition, whereby the original positions of insertion are retained. The functions of the superior and inferior rectus are transferred to the external rectus, by splitting the muscles posteriorly and joining them by means of sutures (fig. 14). JENSEN's method is claimed to produce as good results as that of HUMMELSHEIM without having its disadvantages (FRÜH and HENDERSON, 1971).

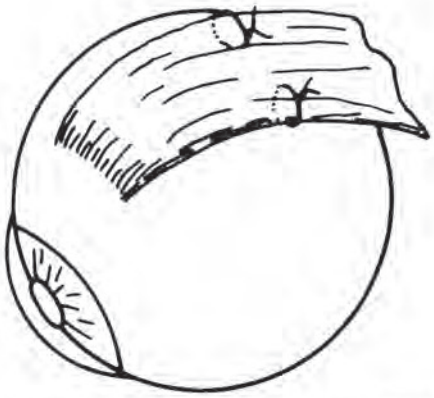


Fig. 14. "Fadenoperation" (myopexia posterior) according to CÜPPERS (1972)

Posterior Fixation Suture ("Fadenoperation" of CÜPPERS)

The *"Fadenoperation"* = suture operation, introduced by CÜPPERS (1972) in Wiesbaden and more precisely described in 1974, belongs to the operations limiting muscle action (CÜPPERS, 1973. 1976). The muscle is fixed 11 to 16 mm behind its original insertion with 2 sutures, tied around the outer third of the muscle belly and secured to the sclera so that a second, dorsal insertion is formed (fig. 15).

Efficacy of muscle contraction is not altered, but the muscle produces considerably less torque, thus causing an artificial ocular muscle palsy without, however, changing the primary position of the eyes. Whilst the customary recessions and resections primarily correct static components, the *"Fadenoperation"* influences the dynamics of strabismus. This method thus introduces a new field of indications, such as unstable deviations, innervational anomalies, nystagmus, and special forms of paralytic strabismus. Within a short span of time, the *"Fadenoperation"* gained worldwide acceptance.

Surgical methods used today

The main concepts of ocular muscle surgery — excepting the "Fadenoperation" of CÜppers and the reintroduction of adjustable sutures — have hardly changed in recent years. The principle to either decrease or enhance the action of the muscle, has existed since the beginnings of ocular muscle surgery; only the methods to reach these goals have changed. No other ophthalmological operations have been modified to such an extent. The methods for exposing the muscle, the placement of sutures, the suture material, the indications, the measurement of recession and resection effects, and many other factors differ

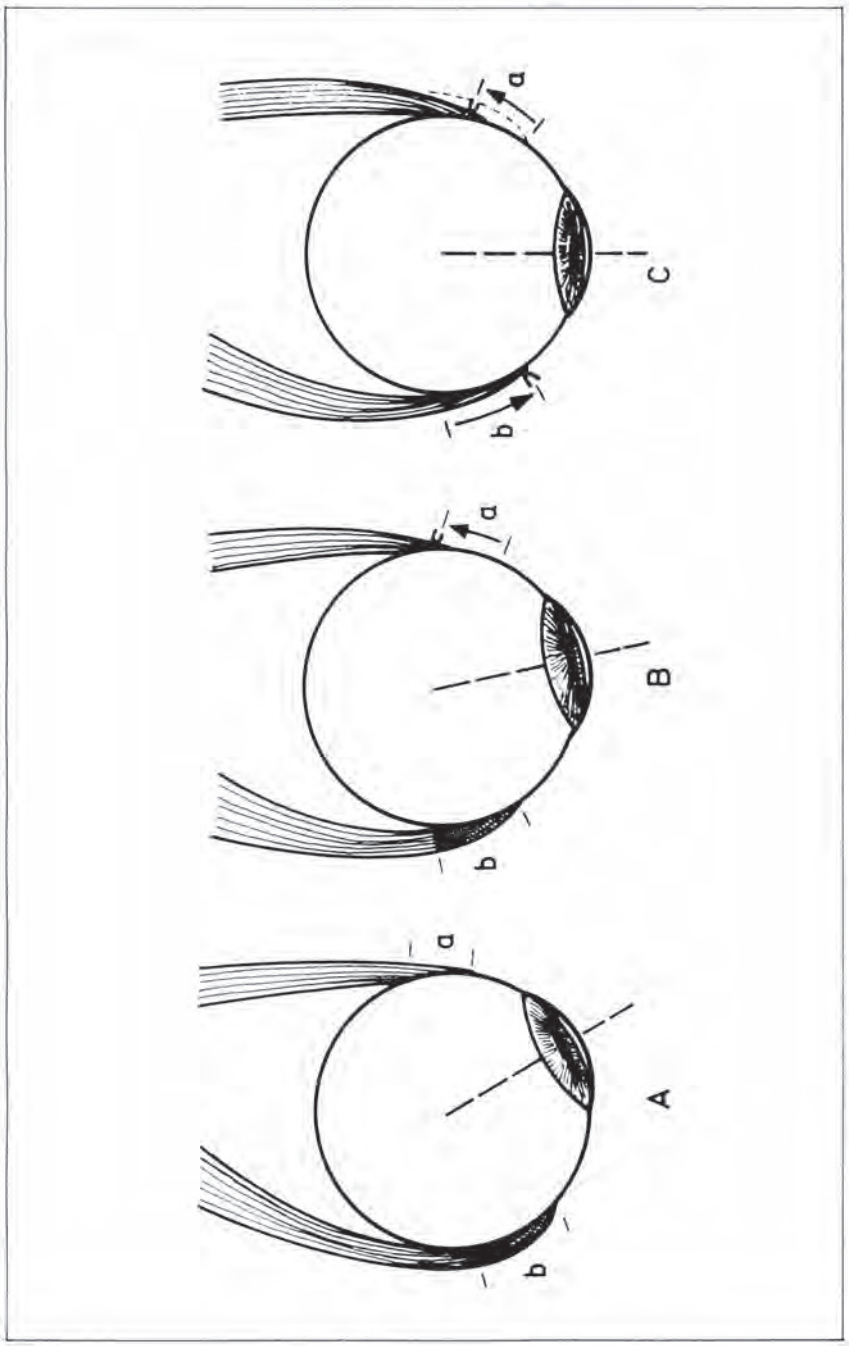


Fig. 15. Combined operation for a convergent deviation (r. e.) A: situation before the operation; B: after recession of internal rectal by length a; C: after resection of external rectus by length b (reproduced from FLICK, 1975)

from surgeon to surgeon, even today. This non-uniformity on one side and the heterogeneous structure of the case material on the other complicate comparisons and hinder general statistical analyses. Thus, in no other field of ophthalmic surgery are the results of surgery influenced to such an extent by the experience and individuality of the surgeon. This applies mainly to the indications and the amount of an operation. For this reason fewer papers on surgical techniques are published, now, as compared to earlier decades.

Up to this day, the combined operation, as first advocated by VON GRAEFE in 1857, is still the most frequently employed procedure (fig. 16). It consists of a graded recession, which limits the action of a muscle, and a resection, which enhances its action. In some cases the bilateral recession of the medial rectus muscles is indicated. The muscle transposition of HUMMELSHEIM and its modification by JENSEN is reserved for rare cases of severe ocular muscle palsies. The *"Fadenoperation"* of COPPERS has introduced a new field, so that today many *"Fadenoperations"* are performed, often combined with recession and resection. The frequency of *"Fadenoperations"* varies in different centres, from less than 20 to more than 50% fall squint operations.

Summary

Among all ophthalmological operations surgical strabismus treatment has the highest degree of uncertainty. This explains the existence of such a plethora of procedures and variations. The development of the different methods is presented. Most of the strabismus operations can be reduced to two principles: (I) Operations limiting muscle effectivity are myotomy, tenotomy (total and partial), tendon lengthening and recession, which can now be graded with adjustable sutures; (II) Operations enhancing the action of the muscle are advancement, tucking, cinching and resection. Amongst the other methods, the muscle transposition and the "Fadenoperation" have gained a certain importance. Today the combined operation (recession and resection or bilateral recession) is the procedure most frequently employed.

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FLICK, H. — Geschichte der Techniken der Augenmuskelchirurgie

Zusammenfassung

Unter allen ophthalmologischen Eingriffen hat die chirurgische Schielbehandlung das größte Unsicherheitsmaß. Daraus erklärt sich die große Zahl von Operationsmethoden und -Variationen. Die Entwicklung dieser verschiedenen Methoden wird dargestellt. Auch heute lassen sich noch die meisten Möglichkeiten der Schieloperation auf zwei Hauptprinzipien reduzieren. Operationen, die die Muskelkraft begrenzen, sind die Myotomie, Tenotomie (totale und partielle), die Sehnenverlängerung und die Rücklagerung. Operationen, die die Muskelkraft stärken, sind die Vorlagerung, die Faltung und Duplikatur und die Resektion. Unter den anderen Methoden haben die Muskeltransposition und die Fadenoperation eine gewisse Bedeutung erlangt. Bis heute ist der kombinierte Eingriff (Rücklagerung und Resektion und die bilaterale Rücklagerung) das am häufigsten angewendete Verfahren.

FLICK, H. — Développement des techniques chirurgicales des muscles oculaires.

Resumé

Parmi toutes les operations ophtalmiques ce sont celles du strabisme qui présentent le plus d'incertitude. Ce fait explique le grand nombre de procédés et de variations. Le développement des différentes méthodes est démontré. Le plupart des opérations pour strabisme peuvent être réduites à deux principes: (1) opérations affaiblissant l'action musculaire (myotomie, ténotomie, totale ou partielle, allongement du tendon et récession; (2) opérations reforçant l'action musculaire (avancement, plissement, duplication et résection). La transposition musculaire et l'opération du „Fil" ont acquis une certaine importance. Actuellement c'est l'opération combinée (récession et résection, et la recession bilaterale) qui est le procédé le plus fréquement utilisé.

DESARROLLO DE LAS TECHNICAS QUIRURGICAS DE LOS MUSCULOS OCULARES

Resumen

De todas las operaciones quirúrgicas en oftalmologia el tratamiento del estrabismo tiene el más alto grado de incertitudes. Esto explica la existencia de tal cantidad de procedimientos quirúrgicos y sus variaciones. El desarrollo de los diferentes métodos está demonstrado. La mayoría de las operaciones de estrabismo pueden reducirse a dos principios: (1) Las operaciones limitando la efectividad del músculo, que son la miotomía, la tenotomia (total y parcial), el alargamiento de tendón y la recesión. (2) Las operaciones permitiendo la acción del músculo, que son el avanzamiento, el plegamiento, la duplicación y la resección. De los otros métodos la transposición del músculo y la operación de hilo han ganado cierta importancia. Actualmente la combinación quirúrgica (de recesión y resección y la recessiòn bilateral) es el procedimiento empleado con más frecuencia.

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