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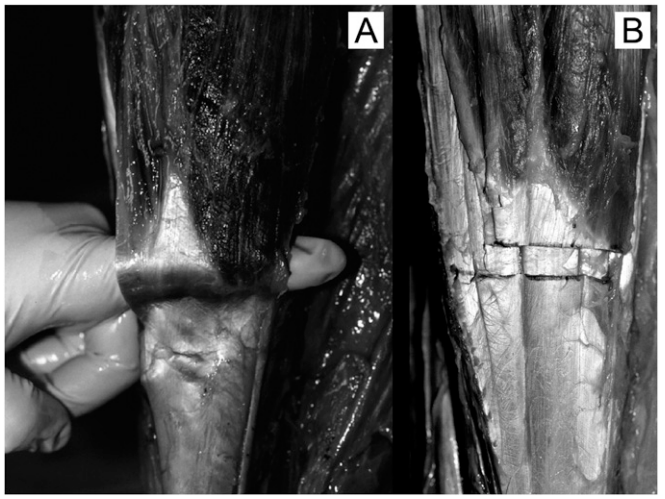

Fig. E-1

Fig. E-1A The demarcation between Zones 1 and 2 is close to the termination of the medial belly of the gastrocnemius muscle, where the two layers (gastrocnemius aponeurosis and soleus fascia) can no longer be separated by blunt dissection. **Fig. E-1B** Transverse division of the gastrocnemius aponeurosis at this point allows the gastrocnemius bellies to recess proximally as described by Strayer. Note that the soleus fascia, which is left undisturbed, is visible in the gap; no muscle fibers of the underlying soleus are visible. This is the major distinguishing feature between this procedure and the gastrocnemius-soleus complex recession described by both Baker and Vulpius.

Fig. E-2

Following division of the gastrocnemius aponeurosis as described by Strayer and illustrated in Figure E-1B, the soleus fascia can be divided transversely and a dorsiflexion force can be reapplied. This is sometimes referred to as a ''modified Strayer procedure'' or a ''Strayer procedure plus soleal fascial lengthening.'' The underlying soleus muscle fibers (including the midline raphé) are now clearly seen. In addition, the 2.1:1 lengthening ratio is noted—i.e., the separation of the gastrocnemius is approximately twice as great as the separation of the soleus fascia. This differential lengthening of the gastrocnemius-soleus complex makes the procedure distinct from the procedures described by Vulpius and Baker.

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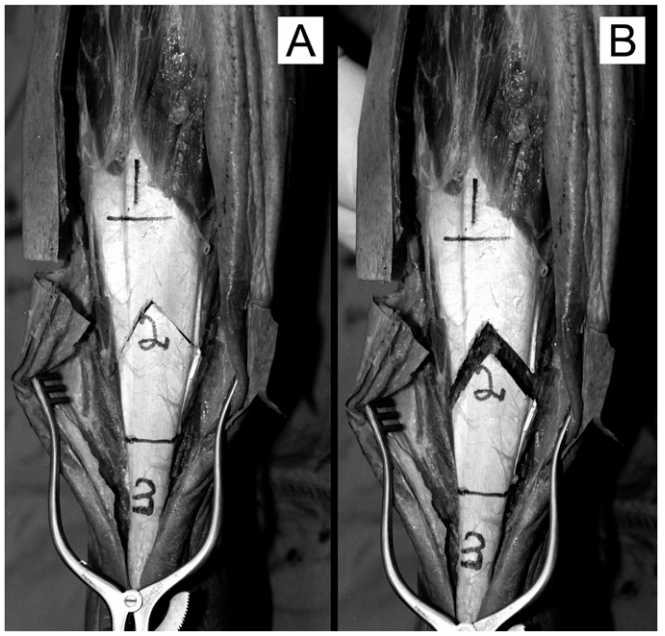

Fig. E-3

The inverted V or chevron cut of the conjoined tendon (gastrocnemius aponeurosis and soleus fascia) as described by Vulpius is seen before (**Fig. E-3A**) and after (**Fig. E-3B**) application of a dorsiflexion force. Anatomical Zones 1, 2, and 3 have been marked on this specimen with use of a skin marking pen.

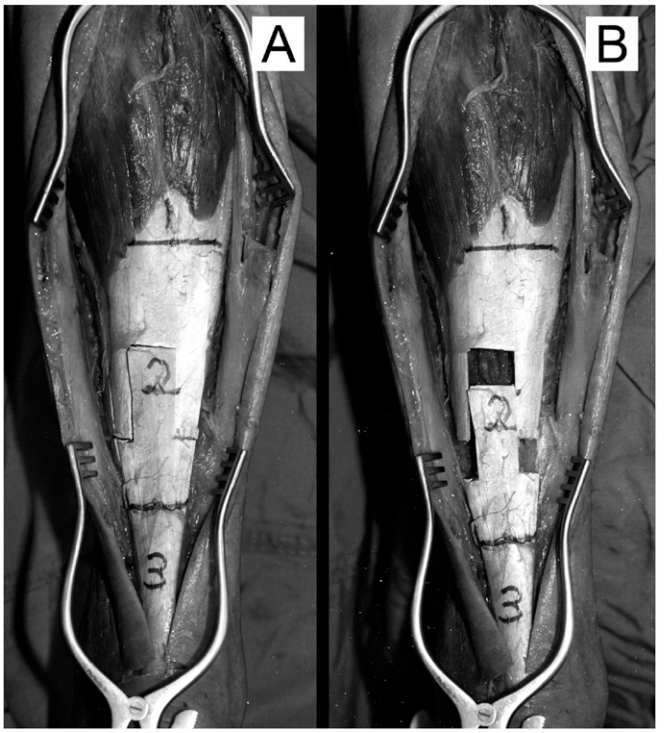

Fig. E-4

The inverted U or ''tongue-in-groove'' cut of the conjoined tendon described by Baker is noted before (**Fig. E-4A**) and after (**Fig. E-4B**) application of a dorsiflexion force. The three anatomical zones are marked.

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Fig. E-5

Slide lengthening of the Achilles tendon by triple hemisection as described by Hoke. Unequal lengthening among the three transverse tenotomies is visible after application of a dorsiflexion force in Figure E-5B and was frequently encountered. In addition, note that the stability of the lengthened tendon depends on the rather weak attachments between the first and second hemisections.

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Appendix 1 Detailed Descriptions of the Surgical Simulations

Baumann Gastrocnemius-Soleus Complex Intramuscular Tenotomy

The interval between the gastrocnemius and soleus was entered from the medial side and opened widely by blunt dissection. The plantaris tendon was divided. Three parallel transverse cuts, which included division of the septum, were made 1.5 cm apart in the proximal half of the gastrocnemius fascia, between the medial and lateral heads[16,22,27]. The dorsiflexion force was applied and the separation of the intramuscular tenotomy cuts was measured. Three parallel transverse cuts, also 1.5 cm apart, were then made in the distal half of the soleus fascia so that there was little overlap between the two sets of cuts. The dorsiflexion force was applied a second time, and the separation of the intramuscular tenotomy cuts was measured a second time.

Strayer Gastrocnemius Recession Combined with Soleal Fascial Lengthening (Figs. E-1 and E-2)

The plane between the gastrocnemius aponeurosis and the underlying soleus fascia was entered from the medial side and widely opened by blunt dissection, as far proximally and distally as possible. The gastrocnemius aponeurosis was divided transversely at the point where the gastrocnemius aponeurosis and the soleus fascia could no longer be separated by blunt dissection. This was always within 1 cm of the termination of the medial muscle belly of the gastrocnemius (Fig. E-1). A dorsiflexion force was applied, and the separation of the divided ends of the aponeurosis was measured[6]. The soleus fascia was then divided transversely, at the same level as the division in the gastrocnemius aponeurosis, and the experiment was repeated. The separation of the gastrocnemius aponeurosis and the soleus fascia were measured separately.

Vulpius Gastrocnemius-Soleus Complex Recession (Fig. E-3)

An inverted V-shaped cut was made through both layers of the conjoined gastrocnemius aponeurosis and soleus fascia, with the apex at the measured midpoint of Zone 2 in the gastrocnemius-soleus complex. The midline raphé was also divided. A dorsiflexion force was applied, and the separation at the apex of the V was measured.

Baker Gastrocnemius-Soleus Complex Recession (Fig. E-4)

An inverted U-shaped cut was made through both layers of the conjoined gastrocnemius aponeurosis and soleus fascia, with the transverse limb of the U cut placed at the measured midpoint of Zone 2 in the gastrocnemius-soleus complex The midline raphé was divided but the distal tongue of the U was not dissected free from the underlying soleus muscle, in accordance with the later descriptions of the Baker procedure. A dorsiflexion force was applied, and the separation of the horizontal limbs of the U was measured.

White Slide Lengthening of the Achilles Tendon by Double Hemisection

The anterior two-thirds of the Achilles tendon was divided distally, 1 cm proximal to the insertion on the calcaneum. The medial two-thirds was then divided 1 cm distal to the termination of the soleus muscle. A dorsiflexion force was applied, and additional fibers were divided at the proximal cut until the yield point was reached and slide lengthening in continuity was achieved. This occurred at between 10 and 15 kg of applied force, by which time the tendon was unable to sustain an applied force of >10 kg. Lengthening was therefore measured at a maximum of 10 kg rather than 40 kg as in the preceding experiments.

Hoke Slide Lengthening of the Achilles Tendon by Triple Hemisection (Fig. E-5)

The proximal end, midpoint, and distal end of the Achilles tendon were marked with a surgical skin marking pen. The lateral half of the Achilles tendon was divided at the levels of the proximal and distal marks. The third cut was made medially at the measured midpoint between the first two cuts. Dorsiflexion force was applied to the metatarsal heads in 10-kg increments, and the hemisections increased equally in width until slide lengthening of the tendon occurred. This occurred at between 10 and 15 kg of applied force, by which time the tendon was unable to sustain an applied force of >10 kg. Lengthening was therefore measured at a maximum of 10 kg rather than 40 kg as in the first four experiments. Lengthening at the three hemisections was not always equal.

Appendix 2 Historical Background of the Vulpius, Baker, and Strayer Procedures

Vulpius described a lengthening of the gastrocnemius aponeurosis and soleus fascia by means of an inverted V-shaped cut in 1913. The direct translation of the German text refers to the "end-tendons" of the gastrocnemius and soleus, and it is clear from both the illustrations and a recent translation of the original article that both layers were sectioned at the same level[5,27]. Baker described a distally based U-shaped cut resulting in "tongue-in-groove" lengthening of the gastrocnemius aponeurosis and soleus fascia in 1954[16]. Previous authors have identified, and the present study confirms, that the description of the procedure varies among the originator's own publications. The results of the Baker and Vulpius lengthening procedures for equinus deformity in patients with cerebral palsy have been reported in many studies[12,16,29,41,46].

The Baker and Vulpius procedures are similar, differing only in the shape of the cut in the combined gastrocnemius aponeurosis and soleus fascia[5,16]. Although Vulpius is associated with the development of the inverted V-shaped cut, it is also worth noting that, according to a translation of his original paper, the cuts may be made "horizontally, diagonally or best of all, in the form of an upside down 'V'. "[5]

The distal gastrocnemius recession described by Strayer consists of a transverse division of the gastrocnemius aponeurosis at the junction of Zones 1 and 2[7]. The plane between the gastrocnemius aponeurosis and the underlying soleus fascia is mobilized and the gastrocnemius bellies are recessed proximally, leaving the soleus fascia and muscle undisturbed. Illustrations in some recent textbooks differ from Strayer's original description in showing soleus muscle fibers exposed by the proximal recession of the gastrocnemius bellies[1,2]. It is quite clear from the original description that the gastrocnemius aponeurosis is divided selectively. Many recent review articles and textbooks nevertheless group the Strayer procedure with the operations described by Baker and Vulpius[2,46,47].

However, the ability of the original Strayer procedure to correct equinus deformity is limited to cases of mild gastrocnemius contracture, as shown in a number of studies[45] and confirmed in the present experimental study. In an effort to extend the range of the Strayer gastrocnemius aponeurosis lengthening, many surgeons divide the soleus fascia after the gastrocnemius aponeurosis when indicated by an intraoperative Silfverskiöld test. There are few descriptions of this procedure in the literature, but it may have originated from the teaching of courses on gait analysis by Dr. James Gage. The gastrocnemius aponeurosis is divided first, and the muscle bellies are allowed to recess proximally by extending the knee and dorsiflexing the ankle. Any persisting equinus deformity would then be caused by a contracture of the soleus, which can be addressed by division of the soleus fascia[27,29,45]. The knee is extended again, and the range of ankle dorsiflexion is checked.

It must be noted that lengthening of the gastrocnemius aponeurosis followed by lengthening of the soleus fascia does not make the combined procedure the same as the Baker and Vulpius procedures. The essential difference is that combined gastrocnemius aponeurosis lengthening and soleal fascial lengthening achieves a differential lengthening of the gastrocnemius and soleus that is close to the 2:1 ratio described as optimal by Delp et al.[43]. In contrast, both the Baker procedure and the Vulpius procedure involve lengthening of the conjoined gastrocnemius aponeurosis and soleus fascia and therefore result in equal lengthening of the two components.

Confusion Between Gastrocnemius Recession and Gastrocnemius-Soleus Complex Recession

In some standard texts[1,2] and recent papers, the gastrocnemius-soleus complex recession first described by Vulpius and then modified by Baker is likened to the gastrocnemius recession described by Strayer. Vulpius described sequential cutting of the end tendons ("Endsehne") of both the gastrocnemius and the soleus at the same level. His illustrations and those for the Baker procedure show separation of the gastrocnemius aponeurosis and the soleus fascia, in continuity, with soleus muscle fibers exposed within the V or U cut. In contrast, the Strayer procedure is a selective distal gastrocnemius recession without any lengthening of the soleus.

The strongest evidence for the crucial anatomical difference between the Strayer procedure and the Vulpius and Baker procedures comes from the discussion following Strayer's presentation to the Annual Meeting of the American Academy of Orthopaedic Surgeons (AAOS) in 1957. Dr. Frederick C. Bost stated, "This operation is entirely different from that described by Vulpius and as performed by many orthopaedic surgeons in the past."

It could be argued that the modification to the Strayer procedure, involving a second cut to the soleus fascia, renders all three procedures alike. However, the modified procedure permits differential lengthening of the gastrocnemius and soleus, which is not feasible with use of the Zone-2 Vulpius and Baker procedures. Given the exquisite sensitivity of the soleus to lengthening, the ability to selectively lengthen the gastrocnemius or to perform differential lengthening of the gastrocnemius and soleus may be important to long-term outcomes in patients with spastic diplegia[12,29,45,49].

Discrepancies in Current Standard Textbooks

The eleventh edition of *Campbell's Operative Orthopaedics*[1] indicates on page 1369 that Strayer believed the operation to be helpful because it altered the proprioceptive impulses received from the extremity, inhibiting abnormal stretch reflexes. It goes on to state, "Many modifications of this procedure have been described including that by Vulpius, in which the aponeurotic tendon of the gastrocnemius is divided and the distal part is allowed to retract distally, but it is not sutured to the soleus."

Two points merit mention. First, Vulpius described his operation in 1913. Therefore, it cannot be a modification of the Strayer procedure, which was not described until 1950. Second, as stated several times in the present paper, Vulpius described an operation in which the gastrocnemius aponeurosis and soleus fascia were both lengthened. This differs from a division of the "aponeurotic tendon of the gastrocnemius."

The fourth edition of *Tachdjian's Pediatric Orthopaedics*[2] states on page 1293 that "Gastrocnemius recession may be done with the techniques of Strayer, Baker, or Vulpius." The chapter goes on to describe aspects of the Strayer, Baker, and Vulpius

procedures, which are grouped together as procedures that lengthen the gastrocnemius. The illustrations of these three procedures on pages 1293 and 1294 do not show a key distinction, which is that only the Strayer procedure represents a true gastrocnemius recession. The color plate on page 1294 shows the muscle fibers of the soleus in the gap, rather than the soleus fascia as indicated in Figure E-1B of the present paper. These textbook illustrations of the Vulpius, Strayer, and Baker procedures all show evidence of gastrocnemius-soleus complex recession, rather than gastrocnemius recession for the Strayer procedure and gastrocnemius-soleus complex recession for the Vulpius and Baker procedures.

Bibliography

The following English translation of part of the German text of the original paper by Vulpius and Stoffel[5] was made by Dr. Jan Matussek (an orthopaedic surgeon from Regensburg, Germany).

Instead of an Achilles tenotomy we can use the final tendons of the Mm. gastronemius and soleus as the operating field with a view to lengthening the M. triceps surae. This intervention is very simple and among its most obvious advantages is that the continuity of the muscle is not even slightly disconnected.

By means of a slightly oblique long cut a little below the middle of the calf, the skin and the fascia cruris are separated. While the assistant brings the foot into a position of dorsal flexion the final tendon ("Endsehne") of the M. gastrocnemius is cut layer by layer either horizontally, diagonally, or, best of all, in the form of an upside down "V." Once the last fibers are cut the tendon stumps will separate out and the foot will already be able to be partially corrected. Deep in the wound one should now be able to see the final tendon ("Endsehne") of the M. soleus which is more or less fused with the gastrocnemius tendon (Fig. 32). With similar cuts this tendon should now be separated. At the base of the wound M. soleus muscle fibers appear, which, if the foot is continually redressed (twisted and turned), can be stretched and partially ruptured without causing a separation in continuity. Its connection with the Achilles tendon remains intact.

In this way one can achieve elongation of 3 cm or more. The distance between the stumps/cut ends of the tendons is later bridged by scar tissue. This method of elongation is further appropriate for all muscles whose final tendons are flanked with muscular fiber. Above all others, those worth mentioning are Mm. extensor digitorum and hallucis longi, peronaei, tibialis anticus, the upper thigh flexors and many lower arm muscles etc. Figure 33 demonstrates the intervention on M. extensor digitorum longus and peroneus longus that was initially recommended by Lange (New York) and further developed by Vulpius. One cuts through the top of the tendon and through slow redressing of the muscle belly and in continual contact with this part, one allows it to stretch so far as is considered necessary for the elongation. ■