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Triggered electromyography-guided progressive fascicular subdivision to identify a functional cleavage plane in conjoined twin spinal cord separation: a dual-configuration case series

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Abstract:

Purpose: Surgical separation of conjoined twins with fused caudal spinal cords requires identification of a safe neural cleavage plane, yet anatomical boundaries are often indistinct. Although triggered electromyography (tEMG) has been used to determine nerve root ownership, a systematic mapping sequence to identify an electrophysiological boundary has not been formally described. This study describes a tEMG-guided progressive fascicular subdivision approach to identify a bilaterally electrically silent cleavage plane in two distinct conjoined twin configurations.

Methods: Two cases (pygopagus and ischiopagus) were monitored using multimodal intraoperative neurophysiological monitoring, including tEMG, transcranial motor evoked potentials, somatosensory evoked potentials, and free-running electromyography. A dual-twin color-coded electrode configuration enabled simultaneous independent mapping of both nervous systems. Progressive fascicular subdivision with re-stimulation of each bundle was performed until a region electrically silent in both twins was identified.

Results: Case 1 involved pygopagus twins with a fused conus medullaris at S2. Case 2 involved ischiopagus twins with a 6-cm syrinx spanning both spinal cords and an anterior sacral myelomeningocele. In both cases, progressive fascicular subdivision identified a functional cleavage plane, defined as a bilaterally electrically silent interval, which guided microsurgical separation. Both pairs of twins were discharged without new neurological deficits.

Conclusion Triggered electromyography-guided progressive fascicular subdivision provides a systematic strategy for identifying the functional cleavage plane during separation of fused caudal neural elements. This mapping approach

was applicable across two distinct conjoined-twin configurations. It remained robust in the presence of complex intrinsic spinal cord pathology, providing a defined electrophysiological endpoint where anatomical landmarks are unreliable.

Keywords

Conjoined twins, Pygopagus, Ischiopagus, Functional cleavage plane, Fascicular subdivision

Introduction

Conjoined twins represent a rare congenital anomaly resulting from incomplete embryologic division of a single fertilized ovum, with an estimated incidence of approximately 1 in 50,000 to 1 in 200,000 live births and a marked female predominance. [12]. Among the recognized configurations, pygopagus twins account for roughly 10 to 18% of cases, and ischiopagus twins for approximately 6 to 11% [12]. In both variants, separation surgery frequently involves the distal spinal canal. When the caudal spinal cords fuse within a shared thecal sac, identification of a safe neural cleavage plane becomes a critical step. Because anatomical boundaries are often indistinct on imaging and inspection, intraoperative functional information is essential for guiding dissection and preserving motor, sphincteric, and autonomic function.

Intraoperative neurophysiological monitoring (IONM) has been incorporated into surgical strategies for the separation of conjoined twins. Triggered electromyography (tEMG) is suited for functional mapping because stimulation of exposed neural tissue can identify nerve root ownership and anatomically indistinguishable cross-innervation patterns. Malhotra et al. [8] demonstrated this principle in a pygopagus pair with fused spinal cords below S2, where tEMG guided identification of root ownership during filum terminale separation. Cromeens et al. [2] showed that stimulation at the inferior apex of a fused spinal segment revealed that both nerve roots at that level belonged to the same twin, prompting modification of the cleavage trajectory from midline to an oblique orientation. Mahmoud et al. [7] reported dual IONM monitoring in a pygopagus pair with a U-shaped fused spinal cord, using tEMG to confirm cross-innervation and guide dissection toward a region producing no responses in either twin. In contrast, Ashari et al. [1] described two pygopagus separations monitored with motor and somatosensory evoked potentials (SSEPs) without tEMG root mapping, reporting transient postoperative motor deficits in three of the four twins, and a fatal outcome in the fourth, despite stable intraoperative recordings.

These reports show that tEMG can guide the separation of fused caudal spinal cords [2, 7, 8]. However, a structured mapping strategy with a prospectively defined intraoperative endpoint has not been clearly formalized. Although the absence of EMG responses has been used as an indicator of a potential separation point [2, 7], prior literature has not defined a systematic process in which progressive fascicular subdivision is followed by repeated stimulation of each subdivided neural bundle. In prior reports, electrically silent regions were identified by stimulating anatomically identifiable root bundles. The present approach differs in that each subdivision step is itself the trigger for re-

stimulation, making the iterative sequence, rather than the anatomical accessibility of a bundle, the operative strategy. This iterative approach permits the identification of a region that is electrically silent in both twins. We refer to this bilaterally silent region as the functional cleavage plane and define it here as a structured surgical endpoint. In addition, the IONM literature remains largely limited to pygopagus anatomy without significant intrinsic spinal cord pathology [2, 7, 8].

In this study, we describe the IONM strategy used during the separation of two conjoined twin pairs with fused caudal spinal cords: one pygopagus pair and one ischiopagus pair with severe intrinsic spinal pathology, including a continuous syrinx spanning both spinal cords and an anterior sacral myelomeningocele. We present a tEMG-guided progressive fascicular subdivision approach to identify a functional cleavage plane and propose a conceptual framework applicable across distinct conjoined twin configurations.

Methods

Both procedures were performed under multimodal IONM to evaluate neural function in each twin while allowing independent interpretation of activation patterns. A dedicated intraoperative neurophysiology technician was assigned to each twin in the pygopagus case. In contrast, individual technicians were assigned to each lower limb in the ischiopagus case to facilitate symmetrical electrode placement. All electrodes were color-coded to prevent channel misidentification, with red labels corresponding to Twin A and blue labels to Twin B. Electrode tracers distinguished laterality, with black indicating left-sided muscles and white indicating right-sided muscles. At the same time, additional wire colors were used intraoperatively to identify segmental levels (Fig. 1).

Subdermal needle electrodes were placed bilaterally in two categories of muscle groups. In both twins, the pilot muscles used for continuous monitoring included the quadriceps, tibialis anterior, gastrocnemius, abductor hallucis, and external anal sphincter. The adductor magnus, hamstrings, and extensor digitorum brevis were additional homologous muscles evaluated for potential cross-innervation. Double sets of concentric needle electrodes were inserted into the external anal sphincter of each twin to assess sacral root activation. The configuration was mirrored symmetrically between twins to permit direct comparison of responses across corresponding channels (Figs. 2, 3).

A multimodal monitoring protocol included SSEPs, transcranial motor evoked potentials (TcMEPs), free-running electromyography (fEMG), tEMG, bulbocavernosus reflex monitoring (BCR), electroencephalography (EEG), and train-of-four (TOF) neuromuscular transmission monitoring. SSEPs were elicited by stimulation of the posterior tibial nerve at the ankle (35 mA, 0.2 ms, 2.7 Hz) and the ulnar nerve at the wrist (20 mA, 0.2 ms, 3.1 Hz), with cortical responses recorded at CPz–CP3/CP4 and CP3/CP4 referenced to Fz or CPz. TcMEPs were obtained using transcranial stimulation through corkscrew electrodes positioned at C1–M3 and C2–M4, delivered as a double-train stimulation with two conditioning pulses and five stimulating pulses (pulse width 0.075 ms, interpulse interval 3 ms, intertrain interval 10 ms), with recordings from upper extremity thenar and hypothenar muscles and from the lower extremity pilot and overlap muscle groups bilaterally in both twins, following a threshold-guided optimization protocol validated

in the same pediatric population at this institution [10]. Both modalities served as continuous surveillance of the ascending sensory and descending motor pathways.

Triggered electromyography was the principal mapping modality used to evaluate sacral root ownership and detect overlapping innervation between the twins. Stimulation was delivered using a handheld flush-tip monopolar probe with a reference electrode placed adjacent to the operative field. Constant current stimulation consisted of repetitive single pulses with a duration of 0.2–0.3 ms at a frequency of approximately 1.1 Hz. Current intensity was increased from 0.1 mA up to a maximum of 5 mA using an ascending stimulation method until compound muscle action potentials (CMAP) were observed in the monitored muscle groups.

During microsurgical exposure of the fused caudal neural elements, tEMG was applied to individual roots to determine their functional distribution. Activation confined to the muscles of the stimulated twin was interpreted as isolated innervation, whereas synchronous responses recorded in the co-twin's homologous muscles were interpreted as evidence of overlapping innervation. In regions where cross-innervation was identified and a clear anatomical cleavage plane could not be determined, the fused neural tissue was progressively subdivided into smaller fascicular bundles under microscopic visualization, with re-stimulation of each isolated fascicle using the same parameters to reassess its functional contribution. This process was repeated iteratively until stimulation produced no electromyographic responses in either twin across all monitored channels. This bilaterally electrically silent interval was interpreted as the functional cleavage plane separating the neural elements of the two twins, and it guided the definitive microsurgical separation of the conjoined spinal cords.

Results

Case 1: Pygopagus twins

Six-month-old female pygopagus twins presented for surgical separation. Preoperative spinal MRI revealed a shared thecal sac with bilateral spinal cord tethering, a fused low-lying conus medullaris terminating at S2, a small central filum terminale lipoma, and a fibrous band bridging both coccyges (Fig. 4). No distinct anatomical cleavage plane between the spinal cords was identified.

TcMEPs were stable and reproducible bilaterally in both twins after induction of total intravenous anesthesia and acquisition of baseline recordings. Lower extremity SSEPs were low in amplitude and inconsistently reproducible. The bulbocavernosus reflex was absent in Twin A at baseline and remained absent throughout the procedure.

Following midline incision and dural opening, the fused conus medullaris and cauda equina were exposed. tEMG mapping was initiated before any neural dissection. Stimulation of the left S2 root of Twin A elicited ipsilateral responses in gastrocnemius and abductor hallucis and cross-twin responses in the hamstrings and extensor digitorum brevis of Twin B, indicating overlapping innervation at S1-S2 (Fig. 5A). Stimulation of the right S2 root of Twin B produced an ipsilateral response in abductor hallucis and a cross-twin response in the extensor digitorum brevis of Twin A, confirming reciprocal overlap at the same segmental level (Fig. 5C). The pattern of cross-activation was

bidirectional but not symmetric, with a broader overlap observed from Twin A's root than from Twin B's, indicating that the shared territory did not align with a simple midline boundary.

Progressive fascicular subdivision was initiated because these findings indicated extensive functional overlap without a clear anatomical boundary. The fused neural tissue was divided into progressively smaller bundles under microscopic visualization, with re-stimulation of each isolated fascicle after each subdivision. With successive subdivisions, the zone of cross-activation progressively narrowed. A region was ultimately identified in which stimulation produced no electromyographic responses in either twin across all monitored muscles, thereby defining the functional cleavage plane and guiding microsurgical separation of the conjoined spinal cords (Fig. 5B, 5D).

TcMEPs remained stable throughout the procedure without deviation from baseline, and no sustained neurotonic activity was observed in fEMG. Both twins recovered without new neurological deficits and were discharged without deterioration in motor or sphincter function relative to their preoperative status.

Case 2: Ischiopagus twins

Twenty-one-month-old ischiopagus twins presented for surgical separation. Preoperative spinal MRI demonstrated a shared thecal sac with cord tethering and a beaded syrinx extending approximately 3.7 cm within Twin A's spinal cord and continuing for an additional 2.3 cm within Twin B's spinal cord, for a total extent of approximately 6 cm. Twin B exhibited a low-lying conus medullaris terminating at S3, leftward sacral angulation, and an anterior sacral myelomeningocele with herniation of the meningeal sac into the presacral space. A segment of the spinal cord extended into the anterior sacral myelomeningocele, with the neural placode visible anteriorly in the pelvis (Fig. 6). No distinct anatomical cleavage plane between the neural elements was identifiable on imaging.

Stable baseline TcMEPs and SSEPs were obtained from both twins after induction of total intravenous anesthesia. A 20-cm midline incision, equally distributed between both twins, exposed the shared dural sac. Following dural opening, the continuity of the neural elements and the absence of reliable anatomical landmarks prevented identification of individual cauda equina structures by inspection alone.

Triggered electromyography mapping was initiated by stimulation of identifiable sacral root bundles. Stimulation of the right S2 root of Twin A elicited an ipsilateral response in abductor hallucis and a cross-twin response in the extensor digitorum brevis of Twin B, indicating overlapping sacral root contribution between twins (Fig. 7A). Stimulation of the left S2 root of Twin B produced the reciprocal pattern, with an ipsilateral response in abductor hallucis and a cross-twin response in the extensor digitorum brevis of Twin A, confirming reciprocal overlap at the same segmental level (Fig. 7B). These findings demonstrated overlapping sacral innervation across both twins. Because these findings did not delineate a clear cleavage plane, progressive fascicular subdivision was initiated.

The fused neural tissue was divided into progressively smaller fascicular bundles under microscopic visualization, and each isolated fascicle was re-stimulated after subdivision. On the Twin A side, early subdivisions produced responses confined to Twin A channels without cross-twin activation (Fig. 8A, 8B), followed by an electrically silent

interval with no responses in either twin across all monitored channels (Fig. 8C). On the Twin B side, subsequent subdivisions again produced responses confined to Twin B channels without cross-twin activation, involving the abductor hallucis and, in one subdivision, the external anal sphincter (Fig. 8D, 8E), followed by a second electrically silent interval that completed definition of the functional cleavage plane and guided microsurgical separation of the conjoined spinal cords (Fig. 8F). Additional tethering was encountered where each cord adhered to the wall of the anterior sacral meningocele. Careful microdissection allowed safe detachment of these attachments, with no triggered electromyography responses detected during stimulation of the meningocele wall.

Near the end of the procedure, Twin B developed significant intraoperative desaturation requiring anesthetic and physiological adjustments. This event was accompanied by EEG suppression and loss of TcMEPs and SSEPs in Twin B, whereas recordings from Twin A remained stable. Preservation of signals in Twin A supported a systemic physiological disturbance rather than primary neurological injury in Twin B. Following correction and hemodynamic stabilization, TcMEPs and SSEPs in Twin B recovered toward baseline. Both spinal cords and thecal sacs were separated with reconstruction of individual dural compartments, and both twins were discharged without new neurological deficits.

Discussion

This report describes a triggered electromyography-guided strategy based on progressive fascicular subdivision to identify a functional cleavage plane during the surgical separation of fused caudal spinal cords in conjoined twins. Although IONM has previously been used to identify sacral root ownership and guide dissection, a systematic mapping strategy with a defined intraoperative endpoint has not been clearly formalized.

Early surgical series of pygopagus separation, including those of Fowler et al. [5] McDowell et al. [9], Hockley et al. [6], and Winder and Law [13], established the feasibility of separating conjoined twins involving the caudal spinal canal but predated systematic IONM protocols or provided limited neurophysiological detail. Subsequent neurosurgical analyses by Fieggen et al. [3, 4] clarified the anatomical basis of shared neural elements and the risks associated with both pygopagus and ischiopagus configurations.

The present cases suggest three specific contributions to the literature. First, they formalize a stepwise mapping methodology based on tEMG stimulation, progressive fascicular subdivision of fused neural tissue, and iterative re-stimulation of each isolated bundle until an electrically silent interval is identified in both twins. Defining this interval as the functional cleavage plane converts a pragmatic intraoperative observation from prior reports into a systematic surgical endpoint rather than an anatomically inferred one. Malhotra et al.[8] demonstrated that tEMG could guide identification of root ownership and inform filum terminale separation in pygopagus twins, thereby establishing the principle of functional neural mapping in this setting. Cromeens et al. [2] provided the most detailed prior account of tEMG-guided surgical decision-making, showing that absent IONM responses together with a small dorsal cleft helped define the superior aspect of the separation plane, while sequential tEMG stimulation of roots at the inferior apex assigned root ownership and shifted the trajectory from an intuitively midline to an oblique course. Mahmoud et

al. [7] guided dissection toward a region that produced no responses in either twin, but did not describe a structured subdivision sequence: the region of bilateral silence was identified by stimulating anatomically accessible root bundles rather than by iterative fascicular subdivision with re-stimulation of each isolated fragment. The methodological contribution of the present cases, therefore, lies not in the observation of bilateral electrical silence alone but in formalizing the operative sequence used to generate, interrogate, and confirm that endpoint. Yokota et al. [14] came closest conceptually to the present approach by describing fascicular subdivision, followed by sequential stimulation, to locate the area of minimal tEMG activity in both twins. Still, their endpoint was defined as minimized rather than as the absence of bilateral activity, and that sequence emerged reactively rather than as a prospectively planned mapping strategy. The present cases extend that prior experience by formalizing progressive fascicular subdivision and repeated re-stimulation as the operative sequence for identifying the functional cleavage plane (Supplementary Table S1).

In contrast, Ashari et al. [1] described two pygopagus pairs monitored with TcMEPs and SSEPs without tEMG root mapping and reported transient postoperative motor deficits in three of the four twins, and a fatal outcome in the fourth, unrelated to neuromonitoring findings. These findings highlight the limitations of pathway surveillance alone when direct functional neural mapping is required.

Second, Case 2 demonstrates the applicability of the same mapping strategy in an ischiopagus configuration complicated by severe intrinsic spinal cord pathology. The existing IONM literature on conjoined twin separation is largely restricted to pygopagus anatomy [1, 2, 7, 8, 14]. In the present study, the combination of a continuous syrinx spanning both spinal cords, a conus terminating at S3, sacral angulation, and an anterior sacral myelomeningocele with presacral herniation made anatomical inference particularly unreliable. Rodriguez-De-Velasco et al. [11] described ischiopagus separation with IONM assistance, but did not detail a comparable neural mapping methodology. The identification of a functional cleavage plane in Case 2, therefore, supports the use of tEMG-guided progressive fascicular subdivision in settings where intrinsic spinal cord pathology obscures anatomical boundaries and increases the value of an electrophysiologically defined endpoint.

Third, the consistent applicability of the same mapping strategy across pygopagus and ischiopagus configurations within the same institutional experience suggests that the functional cleavage plane concept is not configuration-specific.

Several limitations must be acknowledged. The evidence base consists of two cases, supporting a conceptual framework rather than a validated protocol. Reproducibility and generalizability will require confirmation in larger series. Outcome data for autonomic function, including long-term bowel, bladder, and sexual function, remain pending in both cases, and the neurophysiological correlates of autonomic preservation in this population remain incompletely defined. In addition, the absence of bulbocavernosus reflex responses at baseline in Twin A of Case 1 precluded its use as a monitoring endpoint in that twin, illustrating the limitations of individual modalities in the presence of pre-existing sacral pathology. Finally, the intraoperative desaturation in Case 2 illustrated the value of independent dual-twin monitoring, since preserved signals in Twin A indicated a systemic rather than neurological cause.

Future reports should systematically document the number of fascicular subdivision steps required to reach the functional cleavage plane, the criteria used to confirm the electrically silent interval, and long-term outcomes across motor, sphincteric, and autonomic domains. The standardization of these parameters would facilitate cross-institutional comparison and support the development of evidence-based monitoring strategies for this rare and surgically demanding indication.

Triggered electromyography-guided progressive fascicular subdivision provides a systematic strategy for identifying a functional cleavage plane during microsurgical separation of fused caudal spinal cords in conjoined twins. The present cases demonstrate that this mapping strategy can be applied across anatomically distinct configurations and in the presence of complex spinal cord pathology. These findings support the concept of the functional cleavage plane as a practical intraoperative endpoint for neural separation.

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Statements and Declarations

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Authors' contributions

Vizmary J. Montes-Peña: Conceptualization, study design, intraoperative neurophysiological monitoring, data interpretation, and manuscript drafting.

Fayez AlEnazy and Abdullah AlBishi: Intraoperative neurophysiological data acquisition and technical review.

Moutasem Azzubi and Tariq Aljared: Surgical management, interpretation of operative data, and critical revision of the manuscript.

Faisal R. Jahangiri: Conceptualization, study design, neurophysiological interpretation, manuscript critical revision, and supervision.

All authors have read and approved the final version of the manuscript.

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Competing Interests

The authors have no competing interests to declare.

Ethics approval

The Institutional Review Board of the King Abdullah International Medical Research Center (KAIMRC), Ministry of National Guard Health Affairs, Riyadh, Saudi Arabia, approved this study (approval number: NRR26/072/3). All procedures were conducted in accordance with the ethical principles of the Declaration of Helsinki (2013 revision).

Consent to participate

Written informed consent for treatment and data use was obtained from the parents or legal guardians of both twin pairs.

Consent to publish

Written informed consent for publication of clinical data and images was obtained from the parents or legal guardians of both twin pairs.

Data availability

The datasets generated and analyzed in the current study are not publicly available due to patient privacy considerations. Still, they are available from the corresponding author upon reasonable request and with appropriate institutional approval.

Figure 1. Intraoperative IONM electrode setup in conjoined twins.
(A) Pygopagus twins, Case 1. Dedicated IONM technicians simultaneously inserted concentric needle electrodes under a strict color-coded protocol. Red labels correspond to Twin A and blue labels to Twin B. Electrode tracers distinguished laterality, with black indicating left-sided muscles and white indicating right-sided muscles. Additional wire colors were used intraoperatively to distinguish segmental levels.
(B) Ischiopagus twins, Case 2. Superior view of the conjoined twins during electrode placement, with all four lower limbs visible bilaterally. Individual technicians were assigned to each limb to ensure simultaneous and symmetrical needle insertion across all monitored muscle groups. Red and blue labels distinguish Twin A and Twin B recording channels.

Figure 2. Prospective dual-twin intraoperative neuromonitoring schema for detection of cross-innervation during separation of pygopagus conjoined twins (Case 1). Pygopagus twins are shown in parallel cephalocaudal orientation. The central diagram depicts the planned dual-twin IONM channel configuration, with Twin A channels shown in red and Twin B channels shown in blue, organized by spinal level from L2-L4 through S3-S4. Solid lines and filled circles indicate pilot muscles used for primary monitoring: quadriceps (QUAD), tibialis anterior (TA), gastrocnemius (GAST), abductor hallucis (AH), and external anal sphincter (EAS). Dashed lines and open circles indicate additional homologous muscles assigned for overlap assessment: adductor magnus (ADDM), hamstrings (HAMS), and extensor digitorum brevis (EDB). The flanking anatomical panels depict the corresponding bilateral

needle insertion sites used to enable simultaneous, independent monitoring of both nervous systems and intraoperative detection of overlapping sacral root innervation by tEMG.

Figure 3. Prospective dual-twin intraoperative neuromonitoring schema for detection of cross-innervation during separation of ischiopagus conjoined twins (Case 2). Ischiopagus twins are shown in opposing cephalocaudal orientation, resulting in inversion of Twin B relative to Twin A. The central diagram depicts the planned dual-twin IONM channel configuration, with Twin A channels shown in red and Twin B channels shown in blue, organized by spinal level from L2-L4 through S3-S4. Solid lines and filled circles indicate pilot muscles used for primary monitoring: quadriceps (QUAD), tibialis anterior (TA), gastrocnemius (GAST), abductor hallucis (AH), and external anal sphincter (EAS). Dashed lines and open circles indicate additional homologous muscles assigned for overlap assessment: adductor magnus (ADDM), hamstrings (HAMS), and extensor digitorum brevis (EDB). The flanking anatomical panels depict the corresponding bilateral needle insertion sites used to enable simultaneous, independent monitoring of both nervous systems and intraoperative detection of overlapping sacral root innervation by tEMG.

Figure 4. Preoperative spinal MRI of pygopagus conjoined twins (Case 1).
(A) T1-weighted coronal image showing convergence of both spinal columns into a V-shaped configuration toward the shared sacral fusion zone. A common thecal sac is present with bilateral cord tethering. (B) T2-weighted coronal image demonstrating a fused low-lying conus medullaris at the S2 level within the shared thecal sac. A small central filum terminale lipoma and a fibrous band bridging both coccyges are also identified. These findings provided the anatomical substrate for the subsequent intraoperative evaluation of overlapping sacral root innervation by triggered electromyography (tEMG) mapping.

Figure 5. Intraoperative tEMG overlap mapping and functional cleavage plane identification in pygopagus conjoined twins (Case 1).
(A) Stimulation of Twin A left S2 root produced ipsilateral responses in L GAST (L5-S2) and L AH (S1-S2) in Twin A and cross-twin responses in R HAMS (L5-S2) and R EDB (S1-S2) in Twin B, indicating overlapping innervation at S1-S2. (B) After progressive fascicular subdivision, stimulation of the isolated fascicle produced no responses in any channel of either twin, defining the functional cleavage plane. (C) Stimulation of Twin B right S2 root produced an ipsilateral response in R AH (S1-S2) in Twin B and a cross-twin response in L EDB (S1-S2) in Twin A, further supporting shared functional representation at S1-S2. (D) After progressive fascicular subdivision, repeat stimulation produced no responses across all channels in either twin, confirming an electrically silent interval in both twins. Panels A and B show Twin A stimulation, with red channels representing the stimulated twin and blue channels representing overlap-assessment channels in the co-twin. Panels C and D show Twin B stimulation, with

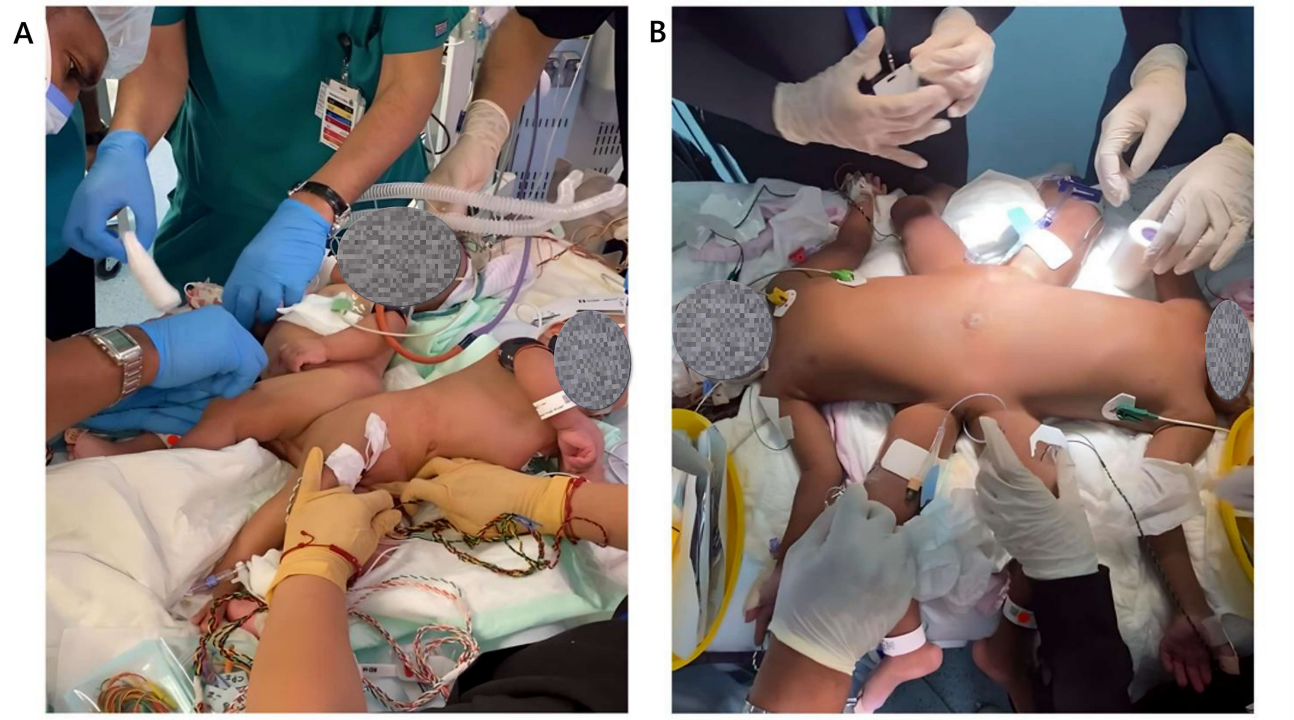
blue channels representing the stimulated twin and red channels representing overlap-assessment channels in the co-twin. Scale: 50 μV/Div, 5 ms/Div.

Figure 6. Preoperative spinal MRI of ischiopagus conjoined twins (Case 2).
(A) T2-weighted sagittal image of Twin A showing a beaded syrinx extending approximately 3.7 cm within the spinal cord. (B) T2-weighted sagittal image of Twin B demonstrating a low-lying conus medullaris terminating at S3, leftward sacral angulation, and continuation of the syrinx for an additional 2.3 cm, for a total extent of approximately 6 cm across both twins. Herniation of the meningeal sac into the presacral space is consistent with an anterior sacral myelomeningocele. (C) T2-weighted axial image demonstrating the shared thecal sac, fused pelvic structures, cord tethering, and extension of a segment of the spinal cord into the anterior sacral myelomeningocele.

Figure 7. Triggered electromyography demonstrating overlapping sacral root innervation in ischiopagus conjoined twins (Case 2).
(A) Stimulation of Twin A right S2 root produced an ipsilateral response in R AH (S1-S2) in Twin A and a cross-twin response in L EDB (S1-S2) in Twin B, indicating overlapping sacral root contribution between twins. (B) Stimulation of Twin B left S2 root produced an ipsilateral response in L AH (S1-S2) in Twin B and a cross-twin response in R EDB (S1-S2) in Twin A, confirming reciprocal overlap at the same segmental level. Red channels correspond to Twin A musculature; blue channels correspond to Twin B musculature. Scale: 50 μV/Div, 5 ms/Div.

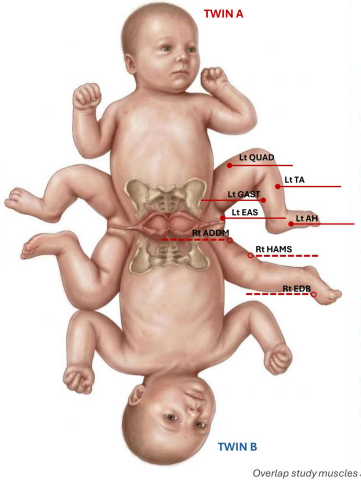
Figure 8. Progressive fascicular subdivision by triggered electromyography defining the functional cleavage plane in ischiopagus conjoined twins (Case 2).
(A, B) Stimulation of subdivided fascicular bundles on the Twin A side produced responses confined to Twin A channels without cross-twin activation. (C) Further subdivision on the Twin A side produced no responses in either twin, identifying an electrically silent interval. (D) Stimulation of a subdivided fascicular bundle on the Twin B side produced a response confined to Twin B's abductor hallucis without cross-twin activation. (E) Stimulation of a further subdivided bundle produced responses confined to Twin B's abductor hallucis and external anal sphincter, again without cross-twin activation. (F) Further subdivision on the Twin B side produced no responses in either twin, completing definition of the functional cleavage plane. Red channels correspond to Twin A musculature; blue channels correspond to Twin B musculature. Panels A to C show Twin A-side stimulation, and panels D to F show Twin B-side stimulation. Scale: 50 μV/Div, 5 ms/Div.

Table 1. Comparison of IONM mapping approaches in the separation of fused caudal spinal cords.

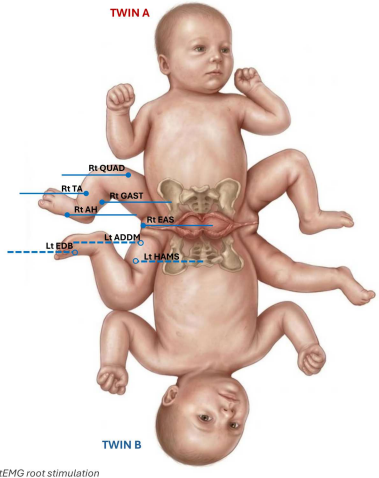

A
B

TWIN B
TWIN A
Panel A: Pygopagus twins — parallel cephalocaudal orientation.
TWIN A
Electrode channels
Spinal Level
TWIN B
Electrode channels
Quadriceps
QUAD
Adductor magnus
ADDM
L2-L4
Quadriceps
QUAD
Adductor magnus
ADDM
Tibialis anterior
TA
L4-L5
Tibialis anterior
TA
Gastrocnemius
GAST
Hamstrings
HAMS
L5-S2
Gastrocnemius
GAST
Hamstrings
HAMS
Abductor hallucis
AH
Ext. digitorum brevis
EDB
S1-S2
Abductor hallucis
AH
Ext. digitorum brevis
EDB
Ext. anal sphincter
EAS
S3-S4
Ext. anal sphincter
EAS
Rt ADDM
Rt HAMS
Lt EAS
Lt QUAD
Lt GAST
Lt TA
Rt EDB
Lt AH
Rt QUAD
Rt EAS
Lt ADDM
Lt HAMS
Rt TA
Rt GAST
Rt AH
Lt EDB
Overlap study muscles are placed at homologous spinal levels to detect potential cross-innervation intraoperatively via tEMG root stimulation
Pilot muscle – Twin A
(primary monitoring)
Overlap study muscle – Twin A
(cross-innervation detection)
Pilot muscle – Twin B
(primary monitoring)
Overlap study muscle – Twin B
(cross-innervation detection)

Panel B: *Ischiopagus twins — opposing cephalocaudal orientation*



TWIN A Electrode channels	Spinal Level	TWIN B Electrode channels
Quadriceps QUAD / Adductor magnus ADDM	L2-L4	Quadriceps QUAD / Adductor magnus ADDM
Tibialis anterior TA	L4-L5	Tibialis anterior TA
Gastrocnemius GAST / Hamstrings HAMS	L5-S2	Gastrocnemius GAST / Hamstrings HAMS
Abductor hallucis AH / Ext. digitorum brevis EDB	S1-S2	Abductor hallucis AH / Ext. digitorum brevis EDB
Ext. anal sphincter EAS	S3-S4	Ext. anal sphincter EAS



Overlap study muscles are placed at homologous spinal levels to detect potential cross-innervation intraoperatively via tEMG root stimulation

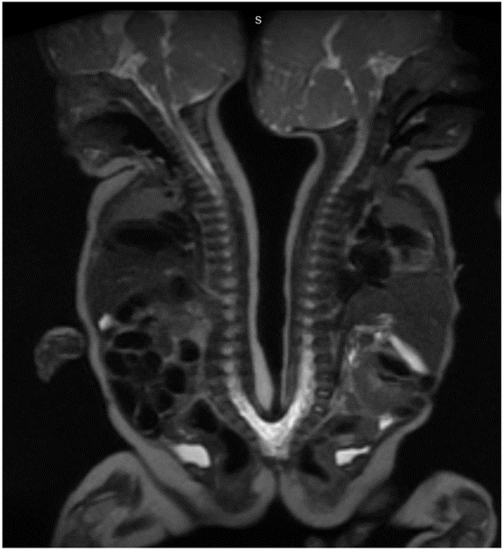
Pilot muscle – Twin A (primary monitoring)

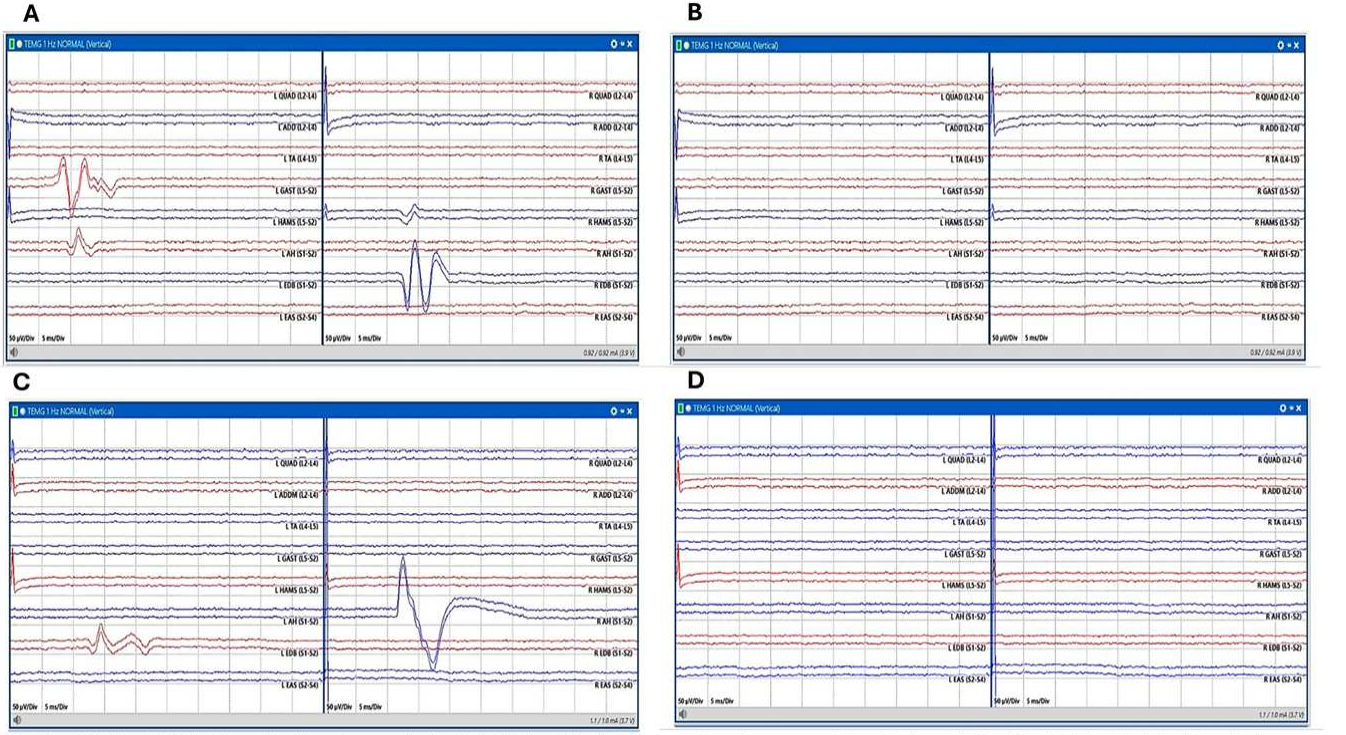
Overlap study muscle – Twin A (cross-innervation detection)

Pilot muscle – Twin B (primary monitoring)

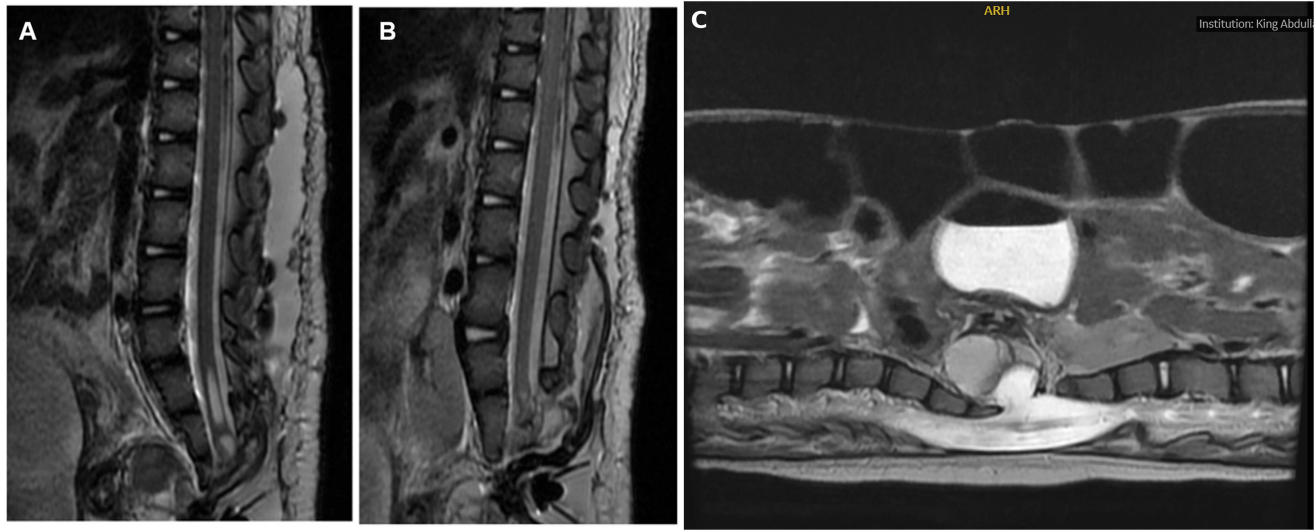
Overlap study muscle – Twin B (cross-innervation detection)


S

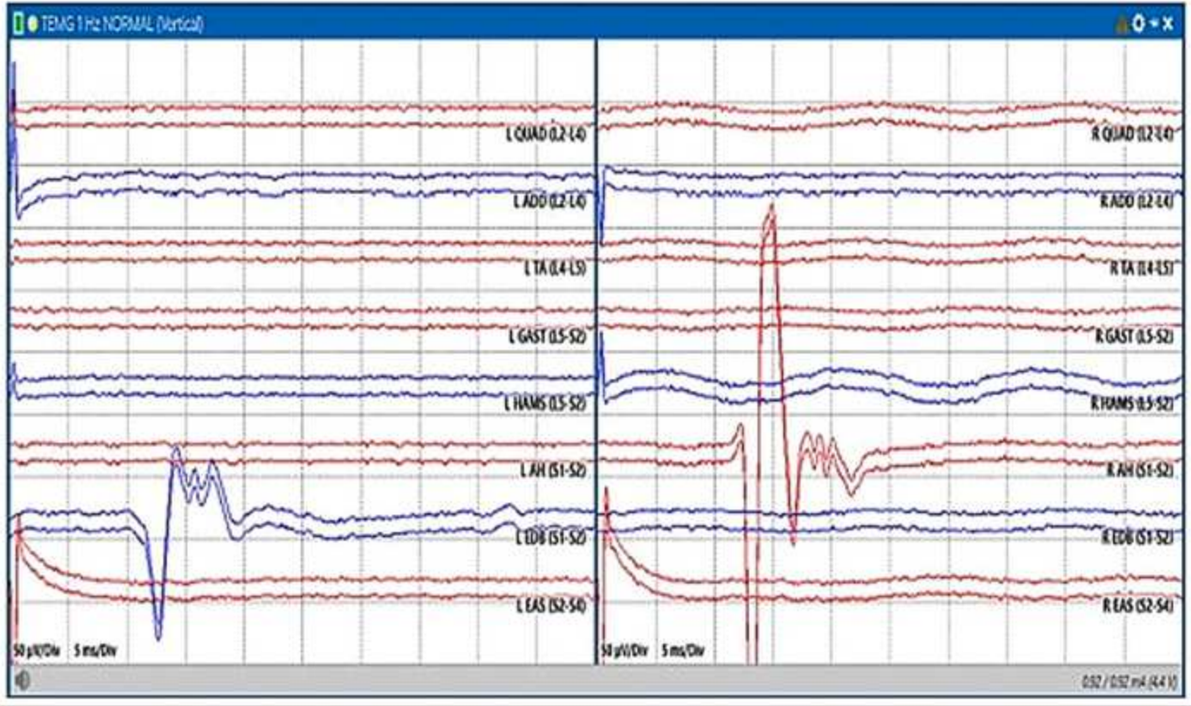

S



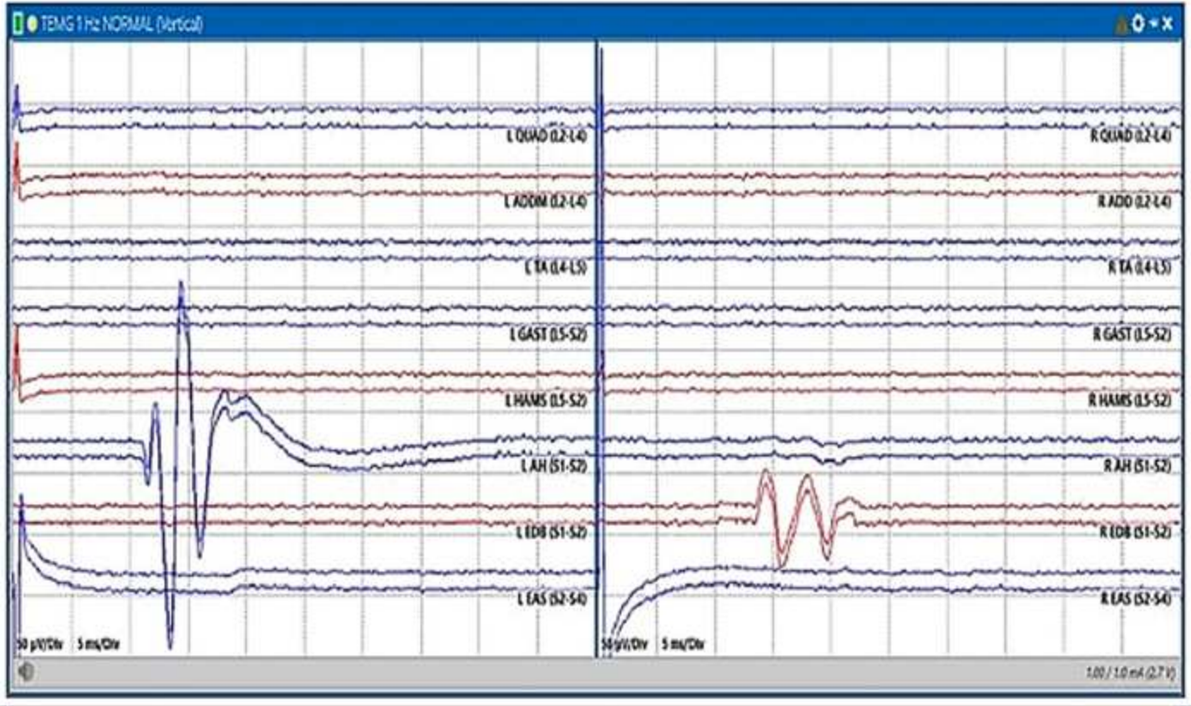
Panel A and B displays Twin A stimulation, with red channels representing the stimulated twin and blue channels representing overlap-assessment channels in the co-twin. Panel C and D displays Twin B stimulation, with blue channels representing the stimulated twin and red channels representing overlap-assessment channels in the co-twin. Scale: 50 µV/Div, 5 ms/Div.


A
B
C
ARH
Institution: King Abdull

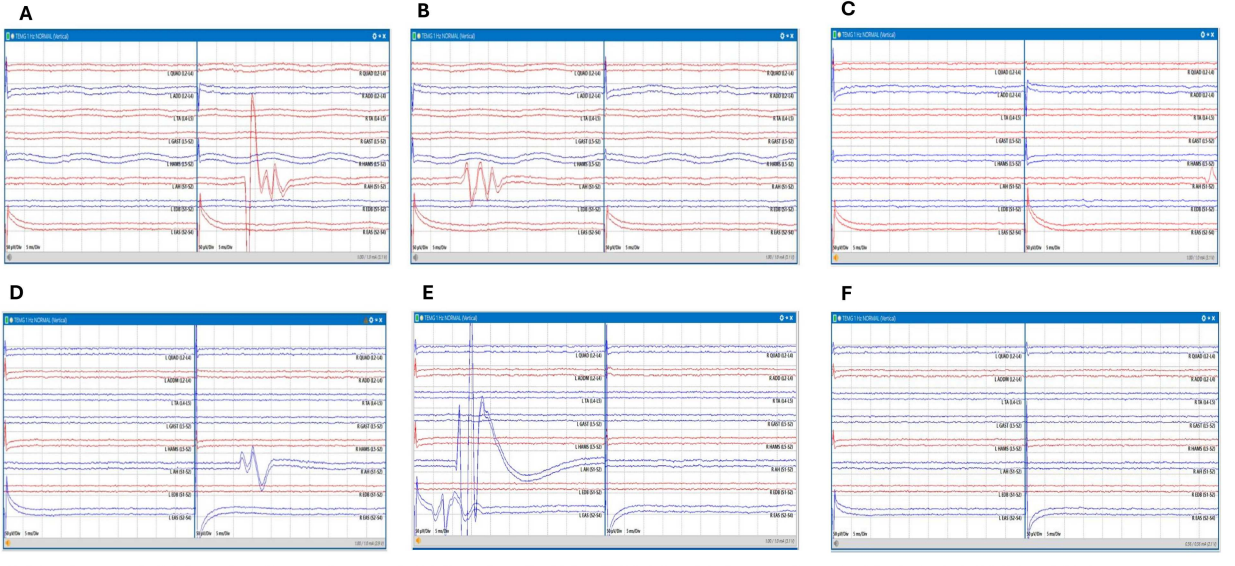
A



B



Red channels correspond to Twin A musculature; blue channels correspond to Twin B musculature. Panel A: Twin A channels (red) represent pilot muscles of the stimulated twin; Twin B channels (blue) represent overlap assessment muscles. Panel B: Twin B channels (blue) represent pilot muscles of the stimulated twin; Twin A channels (red) represent overlap assessment muscles. Scale: 50 µV/Div, 5 ms/Div.



Red channels correspond to Twin A musculature; blue channels correspond to Twin B musculature. Panel A, B, and C: Twin A channels (red) represent pilot muscles of the stimulated twin; Twin B channels (blue) represent overlap assessment muscles. Panel D, E and F: Twin B channels (blue) represent pilot muscles of the stimulated twin; Twin A channels (red) represent overlap assessment muscles. Scale: 50 µV/Div, 5 ms/Div.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Table1.docx