ISSN 1220-8841 (Print)
ISSN 2344-4959 (Online)

ROMANIAN
NEUROSURGERY

Vol. XXXVIII | No. 2 June 2024

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DOI: 10.33962/roneuro-2024-025

Romanian Neurosurgery (2024) XXXVIII (2): pp. 139-148
DOI: 10.33962/roneuro-2024-025
www.journals.lapub.co.uk/index.php/roneurosurgery

Lumbar disc herniation. From epidemiology and neuroimaging to operatory management and postoperative complications

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ABSTRACT

Lumbar disc hernia represents one of the most frequent neurosurgical pathologies, consisting of a posterior migration of the nucleus pulposus which protrudes through the surrounding protective connective tissue. The patient usually exhibits leg pain, paraesthesia or a variable degree of discomfort at the lower extremities, those clinical characteristics are correlated to the extent of nucleos pulposus protrusion. Regarding neuroimaging diagnosis, the gold standard of evaluation is Magnetic resonance imaging in different sequences which highlights a precise topography of the herniated disc. Currently, in a well-digitalized era, machine learning and deep learning algorithms are used to assess the sensibility of detecting a lumbar disc hernia, with promising results. In those cases requiring surgical intervention, besides the open lumbar microdiscectomy, a less invasive surgical approach regularly used in the medical practice is endoscopic lumbar discectomy, being limited to cases where a wide intraoperative perspective is not necessary. In the actual neurosurgical management, postoperative complications following lumbar disc hernia surgery are rare and accessible to manage.

GENERAL DATA

Lumbar intervertebral disc herniation is characterized by the disruption of the annulus fibrosus, attributed to a multitude of factors including lumbar degeneration and sustained strain. This pathological condition leads to the lateral or posterior displacement of the nucleus pulposus,

Keywords
LDH,
LBP,
neuroimaging,
microdiscectomy,
endoscopic techniques,
neuroplasty

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ISSN online 2344-4959
© Romanian Society of Neurosurgery

First published June 2024 by London Academic Publishing
www.lapub.co.uk

which extends significantly laterally or directly posteriorly through the compromised annulus.

Lumbar Disc Herniation (LDH) emerges as a predominant etiology for leg pain, with clinical presentations encompassing a spectrum from mild to severe discomfort in the lumbar region and lower extremities, muscular spasms, sciatica, paresthesia, and reduced muscular strength in the lower limbs. Exceptionally, it may precipitate acute cauda equina syndrome. Activities such as sneezing, coughing, or bending from the waist have been documented to intensify discomfort, adversely affecting the patient's clinical status. Therapeutic approaches to LDH predominantly include conservative management and surgical intervention. Surgical procedures aim to alleviate the pressure exerted by the protruding lumbar discs; nevertheless, they are not devoid of significant risks, including the potential for substantial trauma and the emergence of subsequent symptomatic manifestations (1,2). In contrast, conservative treatments may not furnish substantial pain alleviation in certain instances, with prolonged conditions potentially culminating in complications such as uroschesis or foot-drop.

Contemporary classification paradigms for LDH are predicated upon radiographic findings and pathomorphological characteristics. LDH can be categorized into three distinct types—central, paramedian, and foraminal—based on the specific location of disc protrusion. Furthermore, the degree of protrusion allows for subclassification into bulging, protrusion, or extrusion categories. Additionally, distinctions are made between nonruptured, ruptured, and sequestered discs, guided by the surgical pathomorphological findings (3,4).

Incidence and Pathophysiology

Low back pain (LBP) represents a significant public health issue, exerting a profound impact on a vast demographic, particularly among individuals engaged in extended periods of sitting. Individuals afflicted with LBP often modify their movement patterns as a compensatory mechanism for the diminished functional mobility, employing various strategies (5). This modification potentially leads to either localized or widespread musculoskeletal strain, which is postulated to contribute causatively to the intensification of back-related maladies or discomfort (6).

Contemporary estimations concerning the incidence, prevalence, and disability-adjusted life years (DALYs) associated with LBP denote 245.9 million incidences annually (accounting for 3.2%; ranked as the 15th leading global cause), 577.0 million cases (7.6%; also the 15th leading global cause), and 64.9 million DALYs (representing 2.6% of all DALYs; the 6th leading global cause), respectively. These metrics have exhibited an approximate 50% escalation over the preceding two decades. The overall burden of LBP cases is slightly more prevalent in women than in men, demonstrates a gradual escalation commencing from birth, peaks during the 40–50-year age range, and subsequently exhibits a gradual decrease (7).

Lumbar disc herniation (LDH) constitutes a significant source of morbidity and substantially influences worker compensation claims. The incidence rate of LDH ranges from 1–3%, predominantly impacting male subjects (with males experiencing double the frequency of females) and individuals within the age bracket of 30–59 years (8,9). Notably, LDH prevalence is higher in the lower lumbar spine compared to the upper or middle sections; however, the incidence of herniation at upper levels tends to increase with advancing age (10).

In elderly individuals who have experienced falls, the displacement of the center of gravity from the vertical axis directly above their feet—particularly when elevated on their toes—differs significantly from that of healthy counterparts. With age, the restriction of trunk movement becomes more challenging, leading to an enhanced risk of imbalance. Moreover, medial-lateral (ML) motion is particularly vulnerable to external disturbances and necessitates the activation of dynamic feedback mechanisms, potentially involving visual, vestibular, and other sophisticated central nervous system functions, to ensure stability. The functional decline in older adults complicates the maintenance of balance in the ML direction, especially when faced with unexpected disturbances (11).

Mechanical stress is a pivotal factor in the genesis of disc herniation and the degeneration of facet joints. The persistent application of mechanical stress on one side may lead to unilateral symptoms and asymmetrical deterioration of the intervertebral joints and discs. Additionally, the onset of intervertebral joint arthritis can be prompted by routine activities. For instance, right-handed men are more likely to rotate their spine to the left while engaging in walking or seated activities, suggesting a correlation between the preferred direction of spinal rotation in daily activities and dominant hand usage (8). Previous investigations have highlighted that the left and right sides of the body exhibit varying degrees of lateral flexion and lumbar spine rotation, which implies potential distinctions in the characteristics of left and right LDH, although no disparities between left and right-sided LDH have been conclusively identified.

Neuroimaging: current and emerging techniques

The determination of therapeutic strategies for individuals with intervertebral disc herniation (IDH) is predicated upon clinical assessments and diagnostic imaging results. An initial approach of conservative management is advocated for a duration of 6–8 weeks for patients diagnosed with IDH. Should there be an inadequate response to conservative measures, surgical intervention may be contemplated, with magnetic resonance imaging (MRI) being systematically employed to evaluate the existence of nerve root compression (12).

Research indicates that approximately 10–40% of patients do not experience a marked improvement in symptoms post-lumbar disc surgery, despite advancements in diagnostic and surgical methodologies (13). The suboptimal results observed postoperatively are attributed predominantly to diagnostic inaccuracies, rather than the surgical procedure itself or its associated complications (14). The presence of discrepancies in the interpretation of spinal MRI scans can detrimentally impact therapeutic decision-making, leading to suboptimal clinical management in cases of erroneous positive or negative diagnoses of nerve root compression. The inconsistency in interpreting MRI findings may further complicate the establishment of a correlation between specific imaging features and patient prognoses.

Consequently, it is imperative to comprehend the variability in MRI interpretation among individuals considered for lumbar disc surgery, to enhance diagnostic accuracy and inform optimal treatment pathways. MRI and computed tomography (CT) scans now possess the capability to delineate disc herniations in both intraforaminal and extraforaminal locations with high fidelity. While CT imaging is less efficacious than MRI in identifying radicular compression and exhibits inferior resolution for spinal and paraspinal soft tissues, it demonstrates proficiency in the detection of osteophytes and calcifications (15).

Conventional MRI protocols often do not prioritize the imaging of extraforaminal regions, and visualizing this area, especially at the L5-S1 level, poses challenges due to the overlapping bony structures of the sacral alae and iliac bones. Additionally, degenerative alterations at the L5-S1 disc, which frequently result in a reduction of disc height, complicate the imaging process. Inaccuracies in MRI techniques frequently lead to misdiagnoses. For accurate detection of subtle disc margin aberrations and differentiation of genuine root dislocations from benign asymmetries in root positioning between the two sides, axial slices should be aligned parallel to the intervertebral disc on the sagittal plane. Furthermore, to identify far-lateral herniation, imaging protocols should include paracoronal sections (angled between 15 to 30 degrees) and sagittal sections that extend significantly laterally, covering the entire foramina length. The use of contrast agents is generally not obligatory, although contrast-enhanced imaging may be necessary to differentiate between a sequestered disc fragment and other conditions such as schwannomas. In such instances, fat-saturation pulse T1-weighted spin-echo sequences alongside axial and sagittal T1-weighted spin-echo sequences are recommended. Typically, the sequestered fragment exhibits peripheral enhancement, likely indicative of an inflammatory response in the surrounding tissue (16).

Following images highlights different levels of lumbar disc hernia using MRI in sagittal and axial sections (Fig. 1, Fig. 2, Fig. 3, Fig. 4).

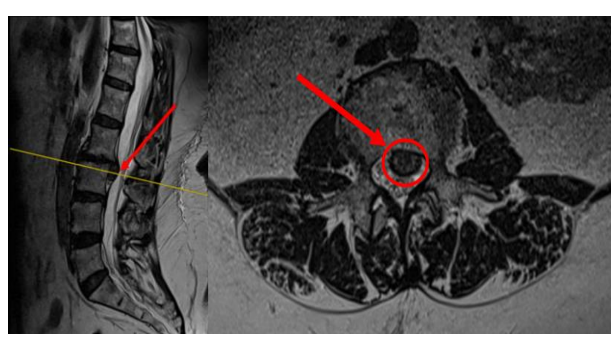

Figure 1. Sagittal section (left) and axial section (right) of a LDH at the level of L2-L3 (Personal case of Prof. Dr. A. V. Ciurea).

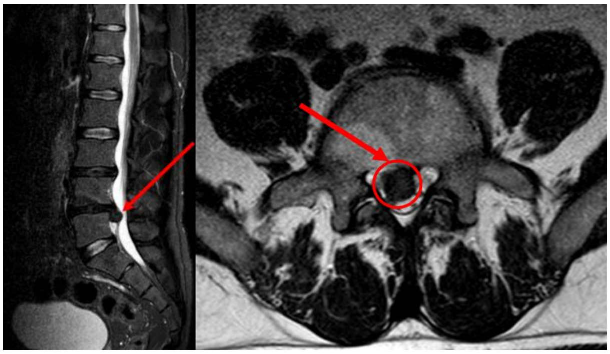

Figure 2. Sagittal section (left) and axial section (right) of a LDH at the level of L4-L5 (Personal case of Prof. Dr. A. V. Ciurea).

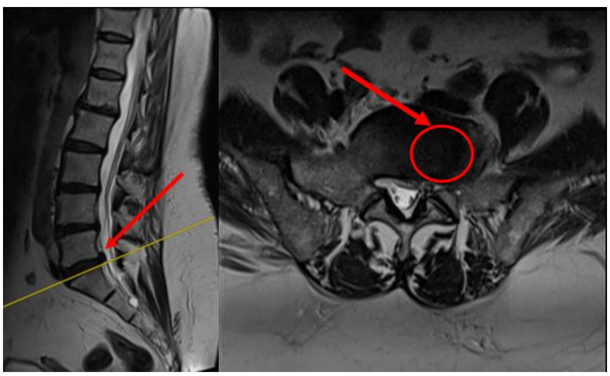

Figure 3. Sagittal section (left) and axial section (right) of a LDH at the level of L5-S1 and spinal stenosis (Personal case of Prof. Dr. A. V. Ciurea).

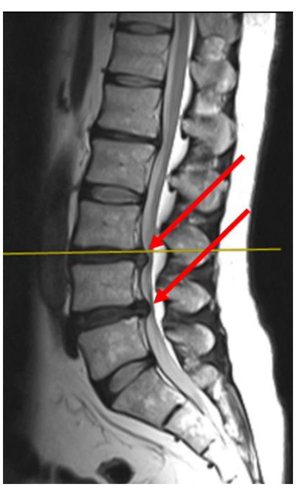

Figure 4. Sagittal section of a multilevel LDH, L3-L4 and L4-L5 (Personal case of Prof. Dr. A. V. Ciurea).

Deep learning architectures are engineered for the rapid and precise identification of images, showcasing their efficacy in enhancing the quality of medical diagnostics within clinical environments. These models significantly augment diagnostic processes and assist healthcare professionals in detecting lesions that may otherwise go unnoticed. Deep learning is particularly beneficial in the analysis of large-scale, repetitive tasks involving the recognition of biomedical imagery. Utilizing sophisticated graphical processing units (GPUs), these methodologies facilitate the computation of intricate features and the automatic classification or recognition of objects within images. Currently, the availability of validated diagnostic MRI images for lumbar vertebrae datasets is limited, underscoring the necessity for the expansion of deep learning models and the enlargement of lumbar MRI data collections (17).

Beyond mere image identification, deep learning is employed to efficiently and iteratively discern critical elements within biomedical images, such as the detection of anomalous and potentially malign lesions throughout the diagnostic evaluation process. Region-based Convolutional Neural Networks (RCNNs) introduce innovative techniques for object detection within images, utilizing a designated object region proposal strategy for CNN training followed by object classification. Subsequent iterations aimed at enhancing processing efficiency, namely Fast-RCNN and Faster-RCNN, strive to refine these complex object detection methodologies, yet challenges persist in achieving optimal deep learning model efficiency. The performance of deep learning is influenced by several factors, including the paucity of images within datasets, which may precipitate overfitting or underfitting scenarios. Previous research has incorporated data augmentation strategies to mitigate data imbalances and minimize overfitting risks in deep learning applications (18). Common data augmentation techniques employed in deep learning encompass Flips, Gaussian Noise, Jittering, Scaling, Powers, Gaussian Blur, Rotations, and Shears (19).

The delineation and pinpointing of distinct discs constitute critical operations in the computer-aided diagnosis of disc herniation. Over the recent half-decade, methodologies rooted in deep learning have redefined benchmarks across numerous domains of computer vision and pattern recognition studies. The aim of this research is to forge an automated framework leveraging a deep convolutional neural network (CNN). This network is designed to analyze input from MRI across various contextual scales, thereafter integrating the extracted high-level features. Such a process amplifies the network's proficiency in identifying discs within the lumbar spine region (20).

Operatory management

Since the advent of the first open discectomy over half a century ago, there has been a significant evolution in surgical methodologies and technological advancements, culminating in procedures that are increasingly minimally invasive. In 1967, Yasargil introduced the utilization of a microscope for discectomy, leading to the development of microdiscectomy (MD) (21). A further reduction in invasiveness was achieved through the introduction of the tubular retractor (TD), which employs a transmuscular route to access the lamina (22). Another innovative approach is the percutaneous discectomy (AUTD), which adopts a posterolateral route. Initially, this procedure was conducted with fluoroscopic guidance alone, but the subsequent integration of endoscopic techniques facilitated the execution of percutaneous endoscopic discectomy (PED) under direct visualization (23).

The primary objective of these surgical interventions remains the excision of disc herniation, typically involving an incision of the disc to extract the herniated material along with the nucleus pulposus contained within the annulus fibrosus (24). Such interventions usually result in the prompt alleviation of radiating leg pain for the majority of patients. However, the degenerated disc and the annular defect are not addressed, which may contribute to a relatively elevated rate of reoperation due to recurrent disc herniation, as additional nucleus material may extrude through the annular breach (25). Previous studies have established a correlation between the size of the annular defect and an increased risk of reherniation, with reported incidences of reherniation varying significantly across studies, ranging from 3-18% (26). A radical approach to mitigate reherniation involves the extensive removal of the nucleus pulposus. However, aggressive discectomy has been associated with a drawback of heightened back pain, likely attributable to expedited disc degeneration (27).

In the 1970s, Caspar and Yasargil pioneered the technique of open lumbar microdiscectomy (OLMD) as a therapeutic intervention for LDH. Characterized by its minimally invasive nature, involving smaller incisions, OLMD demonstrated efficacious outcomes and diminished surgical trauma for patients (28), (29). Consequently, OLMD has been established as the benchmark surgical procedure for the treatment of symptomatic LDH. Despite its successes, OLMD is associated with certain drawbacks, including muscle damage, the necessity for partial laminectomy, and nerve retraction, which may elevate the risk of postoperative lumbar instability and symptomatic epidural scar formation (30,31).

In the early 1990s, in pursuit of enhancing surgical outcomes and minimizing complications associated with LDH interventions, the percutaneous endoscopic lumbar discectomy (PELD), employing either a transforaminal or interlaminar approach, was introduced (32,33). PELD has gained popularity over time, with a substantial body of research indicating its comparability to OLMD in terms of patient outcomes, alongside benefits such as reduced soft tissue damage and improved conservation of bone structure (34,35,36).

Although the incidences of complications common to OLMD, like postoperative spinal instability and epidural scarring, are infrequent with PELD, the technique is not without its challenges (37,38). A significant limitation of PELD is its steep learning curve and the potential for serious complications. Moreover, cases of incomplete decompression during PELD procedures are not rare, necessitating a meticulous morphological assessment of each LDH case prior to opting for PELD as the treatment of choice.

Full-endoscopic spine surgery (FESS) has seen significant advancements over the last thirty years, driven by the evolution of both the instruments employed and the procedural techniques. Initially, full-endoscopic lumbar discectomy (FELD) was designed for implementation via a posterolateral or transforaminal entry. However, the posterolateral route encounters specific challenges at the L5-S1 level, such as a pronounced iliac crest, the least expansive intertransverse space, and a relatively constricted foramen in comparison to superior vertebral levels (39,40). Consequently, interlaminar endoscopic lumbar discectomy (IELD) emerged as a viable solution to navigate the complexities associated with disc herniation at the L5-S1 juncture (41,42). A distinctive aspect of IELD is the likelihood of encountering neural structures prior to reaching the herniated disc, as opposed to the transforaminal approach where the nerve is typically accessed post-herniation removal. Therefore, IELD necessitates precise surgical techniques to mitigate the risks of neural damage and herniation recurrence.

The administration of anesthesia in IELD procedures can be tailored to local, regional (epidural), or general modalities, contingent upon the surgical complexity, the degree of nerve manipulation required, and the surgeon's proficiency (43). General anesthesia is particularly advantageous for securing the airway in patients positioned prone. Procedures characterized by extensive bone removal or spanning multiple vertebral levels may prolong surgery duration, particularly for surgeons with limited experience in these complex scenarios.

A myriad of etiological factors contribute to the persistence of low back pain, encompassing conditions such as spinal stenosis (SS), disc herniation, facet joint pathology, sacroiliac joint dysfunction, adjacent segment degeneration, ligamentous pathology, and failed back surgery syndrome (FBSS) (44,45). Addressing back and leg pain subsequent to spinal surgical procedures presents a formidable challenge. The International Association for the Study of Pain characterizes FBSS as the persistence or recurrence of low back pain, with an undetermined origin, in the same anatomical region, despite the surgical intervention. The genesis of FBSS is multifaceted, influenced by a spectrum of preoperative, intraoperative, and postoperative variables (46). While the precise cause of FBSS remains elusive, a multitude of factors are implicated in its development (47).

Post-surgical epidural adhesions are believed to significantly contribute to the development of epidural fibrosis, a condition associated with FBSS (48,49). Numerous studies have validated the efficacy of percutaneous epidural neuroplasty (PEN) in patients afflicted with FBSS and SS (50,51,52,53). PEN has been recognized as an effective intervention for managing intractable back and leg pain that remains unresponsive to conventional therapeutic approaches, including epidural steroid injections (54).

A treatment modality that occupies the therapeutic niche between conservative management and the administration of epidural steroid injections has been examined in various studies. These studies suggest that between 50% and 87% of patients experience short-term relief (approximately 3 weeks) from symptoms following epidural steroid injection therapy (55,56,57,58). The application of epidural steroid injections is recommended for patients experiencing acute radiating pain and neurogenic claudication that significantly impede daily activities, despite the utilization of analgesics and rest, which are anticipated to mitigate symptoms (59). Moreover, recent research has explored the efficacy of using ropivacaine and dexmedetomidine, in addition to epidural neuroplasty, as adjunctive treatments in thoracolumbar surgical interventions (60,61). Epidural neuroplasty is utilized to address back pain and/or radiating pain arising from mechanical compression on nerve structures within the vertebral column or neuroinflammation. The technique of epidural neuroplasty, including the separation of epidural adhesions with epidural glue, has gained traction and demonstrated promising results in recent times. Nonetheless, there have been reports of serious complications associated with this procedure, including epidural abscesses, irreversible nerve damage, and cardiovascular incidents (62).

Postoperative complications

In the realm of endoscopic lumbar spine surgery, when performed by adept practitioners, complications are infrequent. Nonetheless, endoscopic approaches are not devoid of potential iatrogenic risks, one of which includes the rare but significant risk of operating at an incorrect spinal level. Thus, meticulous examination of preoperative imaging on both sagittal and axial planes is crucial. Accurate radiographic determination of the target level is essential to mitigate the risk of wrong-site surgery. Additionally, precise care is required during the insertion and removal of endoscopic tools to minimize risk.

Comparative analyses have demonstrated that the rates of individual and cumulative complications associated with endoscopic lumbar surgery are significantly lower than those reported for open or minimally invasive translaminar approaches. An aggregate complication rate of 1.42% has been documented by some researchers, with the rate of surgical complications, excluding medical complications, reported at 0.32%—significantly lower than the rates observed in conventional open lumbar spine surgeries. It is noted that approximately 75% of patients undergoing lumbar endoscopy via the transforaminal approach experience a complication-free postoperative recovery.

Considering the full spectrum of complications, which includes durotomy, foot drop, infection (each reported at 0.11%); exacerbation of preexisting medical conditions (0.6%); recurrent herniation of extruded disc fragments (0.6%); postoperative issues such as dysesthesia (12.45%), spinal headaches (0.44%), or surgical site swelling due to irrigation fluid infiltration (3.75%); ecchymosis (0.76%); failure to achieve symptomatic relief (4.35%); and instances of acute care readmission (0.49%), a total adverse event rate of 24.04% has been reported during the postoperative period (63).

A particularly concerning complication of full endoscopic lumbar surgery involves damage to the vascular structures positioned anteriorly and laterally to the spine. Injuries to segmental arteries and major vascular conduits are especially worrisome. Segmental artery injuries are predominantly associated with transforaminal procedures, particularly during the decompression of the exiting nerve root, due to the anatomical path of the segmental artery beneath the exiting nerve root.

Conclusions

Lumbar disc herniation remains one of the most common causes for LBP worldwide. The treatments for LDH have improved in both scope and quality, from interventional pain therapies to various surgical approaches to post-surgical management of recurrence.

Microdiscectomies remain the gold standard surgical approach, and alternative approaches such as tubular discectomies and transforaminal foraminotomy may yield similar symptomatic relief with better clinical outcomes such as lower blood loss and shorter hospital stays.

The exact event leading to disc herniation remains unclear. Non-operative treatments should be the first-line treatment for most patients with lumbar disc herniation. Operative treatment remains the current gold standard, with minimally invasive endoscopic microdiscectomy techniques showing best results with respect to postoperative pain and function. Regenerative medicine is promising.

Endoscopic spine surgery is a popular option in minimally invasive spine surgery with good clinical results in the current scientific literature. With advancement in endoscopic optics, instrumentation and techniques, we can potentially unfold a new chapter of understanding of spine pathologies, and how the pathological processes interact with patients with time as more revision spine surgeries are performed under endoscopic view.

Conflict of interest

The authors declare no conflict of interest, and received no specific funding regarding this scientific research.

Abbreviations

Lumbar Disc Herniation (LDH)
Low back pain (LBP)
Disability-adjusted life years (DALYs)
Medial-lateral (ML)
Intervertebral disc herniation (IDH)
Magnetic resonance imaging (MRI)
Computed tomography (CT)
Graphical processing units (GPUs)
Region-based Convolutional Neural Networks (RCNNs)
Convolutional neural network (CNN)
Microdiscectomy (MD)
Tubular retractor (TD)
Percutaneous discectomy (AUTD)
Percutaneous endoscopic discectomy (PED)
Open lumbar microdiscectomy (OLMD)
Percutaneous endoscopic lumbar discectomy (PELD)
Full-endoscopic spine surgery (FESS)
Full-endoscopic lumbar discectomy (FELD)
Interlaminar endoscopic lumbar discectomy (IELD)
Spinal stenosis (SS)
Failed back surgery syndrome (FBSS)
Percutaneous epidural neuroplasty (PEN)

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