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Biocompatibility and mechanisms of aseptic inflammation in the use of suture materials in surgery

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Any suture material intended for medical use must be characterized by a high level of biological compatibility. Biocompatibility is generally considered to be a material's ability to interact harmoniously with living tissue, its «affinity» with the body, which minimizes negative immune and inflammatory reactions.

Aim – to evaluate contemporary suture materials in terms of their physical and mechanical properties, biocompatibility, and effects on body tissues, as well as to determine the advantages of synthetic absorbable materials compared with traditional natural threads.

The analysis was conducted based on contemporary literature sources available in the PubMed, Scopus, Web of Science databases and experimental and clinical data concerning the use of suture materials in surgery. At the current stage of development of surgical practice, suture material must demonstrate a high level of biological activity, and, first of all, demonstrate the ability to resist infectious agents. The best thread should have the following basic properties: have the highest possible tensile strength, have knot stability in dry and wet conditions, have a relative elongation of the thread within 25±10% and a minimally high Young's modulus, be atraumatic, have an optimal thread surface texture, have balanced hydrophilicity, have non-pyrogenic properties, and cause a minimal tissue reaction of the local immune system during absorption.

Conclusion. Synthetic suture materials (both absorbable and non-absorbable) represent an optimal choice for contemporary surgery due to their high biocompatibility, predictable mechanical properties, controlled resorption, and minimal tissue reaction. Their use contributes to improved surgical outcomes and a reduced incidence of postoperative complications.

No conflict of interests was declared by the authors.

Keywords: aseptic inflammation, absorbable suture material, non-absorbable suture material.

Біосумісність і механізми асептичного запалення при використанні шовних матеріалів у хірургії

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Будь-який шовний матеріал повинен характеризуватися високим рівнем біологічної сумісності. Поняття біосумісності зазвичай розглядають як здатність матеріалу до гармонійної взаємодії з живими тканинами, його «спорідненість» із організмом, що забезпечує мінімізацію негативних імунних та запальних реакцій.

Мета – оцінити сучасні шовні матеріали з огляду їхніх фізико-механічних властивостей, біосумісності та впливу на тканини організму, а також визначити переваги синтетичних абсорбуючих матеріалів порівняно з традиційними натуральними нитками.

Проведено аналіз літератури на основі сучасних літературних джерел представлених у базах даних PubMed, Scopus та Web of Science, експериментальних та клінічних даних щодо застосування шовних матеріалів у хірургії. На сучасному етапі розвитку хірургічної практики шовний матеріал має відповідати високим вимогам щодо біологічної активності, а першочергово – демонструвати здатність протидіяти інфекційним агентам. Найкраща нитка має мати такі основні властивості: володіти максимально можливою міцністю на розрив, стійкістю вузла в сухому та вологому середовищі, відносним подовженням нитки в межах 25±10% та мінімально високим модулем Юнга, атравматичністю, оптимальною текстурою поверхні нитки, збалансованою гідрофільністю, апірогенними властивостями та викликати мінімальну тканинну реакцію місцевої імунної системи під час абсорбції.

Висновок. Синтетичні шовні матеріали (як абсорбуючі так і не абсорбуючі) є оптимальним вибором для сучасної хірургії завдяки високій біосумісності, передбачуваності механічних властивостей, контрольованій резорбції та мінімальній тканинній реакції. Використання таких матеріалів сприяє покращенню результатів оперативного лікування та зниженню частоти післяопераційних ускладнень.

Автори заявляють про відсутність конфлікту інтересів.

Ключові слова: асептичне запалення, абсорбуючий шовний матеріал, не абсорбуючий шовний матеріал.

Introduction

A living organism is represented by a wide spectrum of diverse cells formed by biomolecules of various natures, types, forms, and kinds, which ensure the performance of specific physiological functions and the maintenance of homeostasis. Each cell is an integral unit of the living organism and responds to changes in the surrounding environment, including the appearance of foreign agents. The contact of the organism with foreign structures triggers a complex set of immune and physiological reactions aimed at their recognition and, if necessary, rejection [2,29,32].

Regardless of the nature of the foreign material, whether it is a biological substance used for implantation, a metallic alloy, or a synthetic polymer, the establishment of a favorable interaction between the organism and the material remains an exceptionally complex challenge [29,47]. Achieving biocompatibility requires consideration not only of the chemical and physical properties of the material but also of its effect on cellular processes, local immune responses, and long-term tissue integration. Successful resolution of this issue ensures the stable and safe functioning of an implant or other biomaterial structure within the organism, which is of critical importance in contemporary medicine, biotechnology and surgical practice [19,29,47].

Therefore, any material intended for medical use must be characterized by a high level of biological compatibility. The concept of biocompatibility is generally understood as the ability of a material to interact harmoniously with living tissues, its «affinity» with the organism, which ensures the minimization of adverse immune and inflammatory responses. Substances possessing this property constitute a wide range of biomaterials, including, in particular, materials used for surgical sutures. Such materials must be capable of resorption after a defined period of functional activity, most often through enzymatic degradation, without causing harm to the organism [11,19,29,32,38,45].

At the same time, one of the factors that may contribute to the development of an inflammatory process following surgical interventions is residual suture material. It acts as a foreign agent to the organism and may subsequently cause postoperative complications, including infectious and septic processes [19,29,45]. Ensuring a high level of biocompatibility of suture material is therefore critically important for reducing the risk of such complications and for supporting normal tissue regeneration.

The aim of the study is to evaluate contemporary suture materials in terms of their physical and mechanical properties, biocompatibility and effects on body tissues, as well as to determine the advantages of synthetic absorbable materials compared with traditional natural threads.

The analysis was conducted based on contemporary literature sources available in the PubMed, Scopus, and Web of Science databases, as well as experimental and clinical data concerning the use of suture materials in surgery. The study considered the physical and mechanical characteristics of the threads (tensile strength, Young's modulus, atraumatic properties, hydrophilicity, and resorption rate), as well as their biocompatibility and effects on tissue regeneration processes in animal models and clinical settings. In addition, morphological and morphometric changes in tissues were analyzed following the implantation of catgut, silk, polyglycolic sutures, polydioxanone, and modified polypropylene.

The outcome of any surgical treatment depends on the proper use of suture material. Every surgeon must be familiar with the physical characteristics and properties of the suture material employed during surgical procedures [16]. At the current stage of surgical practice development, suture materials must meet high standards of biological performance and, above all, demonstrate the ability to resist infectious agents [2,4,7,12,13,26,31,33]. The main characteristics of suture materials include the following:

The maximum possible tensile strength, which allows the use of a minimal amount of thread when placing a suture. This, in turn, reduces the volume of foreign material within the organism, minimizes tissue reaction, and promotes rapid, scar-free wound healing.

Knot stability in both dry and moist environments should remain as close as possible to the original tensile strength of the thread. An important consideration is that when the knot comes into contact with tissue fluid, its strength decreases sharply, which must be taken into account during surgical suturing.

Relative elongation of the thread within 25±10%, ensuring approximation of healthy tissues without excessive tension and with sufficient blood supply. The literature presents differing opinions regarding optimal elongation: some authors report 7–10%, while others suggest 30–35%; beyond these limits, tissue cutting may occur.

Young's modulus should be relatively low while maintaining sufficient tensile strength. This provides good handling characteristics, flexibility, and compliance of the thread during surgical manipulation.

Atraumatic properties, determined by the condition of the thread surface, Young's modulus, and the method of attachment to the needle, allow for minimal tissue trauma during suturing.

Optimal surface texture: the thread should not be overly smooth to prevent knot slippage, while the absence of roughness prevents tissue damage due to a «sawing effect».

Hydrophilicity, i.e., the ability of the thread to swell upon contact with tissue fluid, which may reduce its strength; this property must be balanced with the mechanical characteristics of the thread.

Proportionality between the rate of strength loss and the wound healing process, ensuring adequate tissue support until the restoration of natural tensile strength.

Complete resorption of the thread until its full disappearance and, importantly, the degradation products must be non-toxic, should not accumulate in parenchymal organs, and must be completely excreted from the body.

Minimal tissue reaction during suturing, which depends on the chemical structure of the thread, its absorption mechanism and its ability to prevent the penetration of microorganisms. The «wicking effect» of the thread is also crucial: the higher its capillarity and hydrophilicity, the greater the likelihood of fluid and microorganism accumulation within the suture channel.

Thus, the requirements imposed on materials intended for medical use are extremely diverse and multifaceted; therefore, clearly defining the concept of biocompatibility and providing an unambiguous and comprehensive characterization of it is an exceptionally complex task. It is necessary to consider the specific meaning of compatibility in relation to the intended purpose of each individual biomaterial. When a foreign material is implanted into the organism, the body immediately mounts a strong response against this substance, with the direction and mechanisms of these reactions varying widely. The primary requirement that medical materials must meet is that they should not cause harm to the organism. Consequently, it is essential to possess comprehensive information regarding which factors inherent to the material may be harmful to the body [7,31–33].

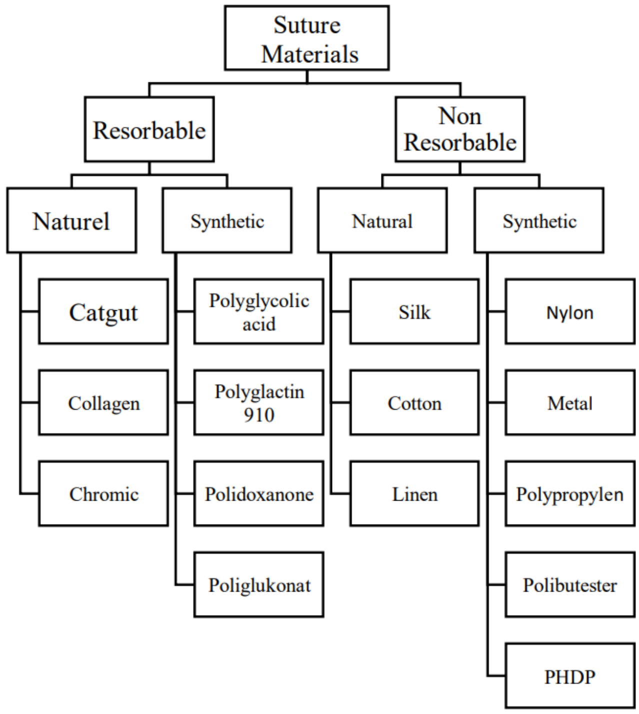

Fig. Types of suture materials (taken from Comparison tensile strength of different sutur materials) [28]

Suture materials, or materials for surgical stitching, are used during surgical interventions to join various tissues [33,45]. Rarely is a surgical operation performed without the application of sutures. Materials such as silk, catgut, synthetic threads, metal staples, metal wire, horsehair, and threads made from deer tendons, among others, are used as suturing materials. Such diversity of materials is explained by the differing properties of the tissues being sutured and the varying periods required for their healing. This necessitates materials with different levels of mechanical strength. Surgical silk and catgut are most commonly used for suturing and serve as the main suture materials in surgical practice (Fig.).

Surgical suture threads, like other biomaterials, are classified into those based on metallic, natural and synthetic materials and, depending on their field of application, come in various diameters. The natural (organic) resorbable materials include plain catgut and chromic catgut, which is specially treated with chromium salts to increase the duration of its biodegradation [28].

One of the most common natural resorbable suture materials still used by surgeons today is catgut [22,27].

S.V. Honchar studied reparative tissue regeneration in the kidney when using resorbable catgut sutures by performing nephrotomy and closing the nephrotomy wound with polished catgut made from ovine raw material, and for suturing the kidney wound, catgut made from porcine raw material and catgut modified with L-arginine were used. As a result, L-arginine-modified catgut did not cause significant or prolonged changes in microcirculation but instead stimulated angiogenic activity in young connective tissue as early as the third day of observation. This improves scar oxygenation and promotes faster maturation of connective tissue [15].

Catgut is widely used for suturing internal organs and tissues, which is explained by its ability to be absorbed in the body within 2–4 weeks, depending on the thickness of the thread [1,27]. However, experience has shown that it has significant disadvantages due to its natural origin. Catgut is produced from animal raw material and consists of collagen fibers with a considerable admixture of non-collagenous proteins, which causes it to have an allergenic effect on surrounding tissues, especially when reused in the same patient. The tensile strength of catgut is lower than that of most synthetic resorbable suture materials, and its knot-breaking load is relatively small and varies considerably. In the moist state, knot strength may become critical due to thread swelling. Catgut also has a very high Young's modulus, making it stiff, difficult to handle and prone to cutting through tissues.

The rapid decrease in strength *in vivo* makes it unsuitable for use under conditions of tissue tension. The absorption period of catgut is not only unregulated but also unpredictable, as it depends on numerous factors. The inflammatory reaction to catgut is characterized by a pronounced exudative nature, ending later with fibrosis and sometimes a granulomatous response. The exudative inflammation includes an allergic component, with a high presence of lymphocytes and eosinophils in the affected area. Tissue edema and the presence of polymorphonuclear leukocytes persist for a long time, even when the suture thread itself is no longer detectable in the suture canal. Such an intense inflammatory reaction is associated with the protein nature of catgut and the difficulty of its sterilization. Its polyfilament structure also contributes to bacterial contamination: the interfilament spaces become filled with exudate, which serves as a nutrient medium for bacteria.

V.H. Hryn et al. investigated the role of the local immune system of the abdominal cavity in experimental animals by implanting a bundle of catgut thread (2/0) into the peritoneal cavity. In all cases, the mechanisms of the local immune system were activated through the capture and rejection of the foreign substrate by the greater omentum or epididymal omenta. Morphologically, this was visualized by the presence of blood vessels growing into the implant and the formation, along the entire length of the catgut thread, of a continuous, dense layer of immunocompetent cells in the form of a peculiar sheath, mainly composed of lymphocytic and phagocytic elements. Therefore, the process aimed at rejecting the catgut thread, regardless of its duration, depending on the individual characteristics of the animal, is accompanied by a sluggish course of aseptic inflammation in the peritoneal cavity [21,22].

Surgical silk has high strength and durability, making it a commonly used non-resorbable suture material. Other non-resorbable suture materials include domestic Kapron (twisted polyamide), braided polyamide, monofilament polyamides, Lavsan, Dacron (braided polyester), steel, and monofilament polypropylene. In recent years, considerable attention has been given to finding suitable materials for producing bioresorbable surgical threads. A bioresorbable surgical suture material should reliably maintain the integrity of surgical stitches, possess sufficient elasticity, and gradually resorb at a rate corresponding to the tissue healing process. The degradation products of such materials must be easily eliminated from the implantation site, be completely harmless to the body, and not cause adverse reactions either from the surrounding tissues or from the organism as a whole [24,25,31,45,48].

Synthetic resorbable suture materials include polyglycolic acid threads based on modified polyglycolide lactide, which possess high strength and flexibility, as well as Dexon, a synthetic copolymer of glycolic acid, and Polysorb [4]. Polyglycolic acid (Dexon) was the first synthetic resorbable surgical suture material, which appeared on the global market in 1968. This was followed by polyglactin-910 (Vicryl) in 1972, polydioxanone in 1980, and later by polytrimethylene carbonate-lactomer 9–1 (Polysorb).

One of the main advantages of synthetic resorbable suture materials is their high biological inertness, as they cause almost no tissue reaction. Since all the synthetic resorbable sutures listed above are chemically composed of polymers of glycolic acid or combinations of glycolic and lactic acids in various ratios, the differences in tissue response are primarily determined by the physicomechanical properties of the thread from which they are made, such as the braiding pattern, the presence of a coating, filament structure, etc. [6,7,41].

An important component in studying the biological properties of suture materials is experimental research and modeling of pathological conditions in animals [20,23].

In experimental studies on laboratory animals, many authors have demonstrated the use of polyglycolic acid threads for muscle suturing; monofilament synthetic resorbable suture material «PDS» (polydioxanone), comparing it with traditional suturing using Kapron thread; the effectiveness of intra-abdominal implantation of prostheses made of polypropylene and polyvinylidene fluoride (PVDF) into the abdominal wall of animals has also been studied; as well as the use of various types of suture materials: Vicryl, polydioxanone, Kapron and silk in surgical procedures on the small intestine [3,30,34].

R.V. Skoruk reports that the use of multifilament suture materials made of silk and Kapron for tissue approximation is inadvisable, as their implantation into tissues provokes a pronounced inflammatory reaction. Polypropylene threads modified with silver nanoparticles exhibit stable antimicrobial activity, which persists in tissues after implantation into the liver and skeletal muscles for up to 30 days. Therefore, the author concludes that it is the modified polypropylene threads that can be used for tissue approximation in surgical infections [42].

Some of the biological properties of suture materials used in open (cavity) surgeries are illustrated below through clinical examples.

The use of polyglycolic acid threads for suturing anastomosis in the large intestine following resection due to tumor or inflammatory diseases reduces the incidence of anastomotic insufficiency by half compared to the use of catgut for the same purpose [8].

In urinary tract tissues, synthetic resorbable suture materials elicit a mild reaction; however, due to their braided structure, polyglycolic acid and polyglactin-910 threads can occasionally serve as a nidus for stone formation. Nevertheless, owing to their biological inertness, encrustation of the sutures with salts occurs very rarely – less frequently than with catgut and even more so than with non-resorbable suture materials [9,35].

The tissues of the uterus and its appendages exhibit minimal reaction to the implantation of synthetic suture materials. The degree of fibrosis development in the area of tubal anastomosis directly depends on the type of suture material used. The use of synthetic resorbable sutures is associated with a minimal fibroplastic response [25].

The findings of morphological and radiological studies are supported by tensometric results. It has been established that by day 8, a sharp decrease in the mechanical strength of the anastomosis when using catgut was notable, primarily due to pronounced inflammatory changes in the suture zone, as well as softening and fragmentation of the catgut thread. In contrast, the use of synthetic resorbable suture materials is not accompanied by a significant inflammatory reaction, and the thread retains its original properties for a prolonged period [17,25].

The chemical structure of the polymer from which a surgical suture material is made can exert a direct toxic effect on surrounding tissue cells, causing necrosis or increasing the virulence of opportunistic microorganisms within the site of aseptic inflammation, thereby promoting the acquisition or restoration of pathogenic properties by saprophytic and conditionally pathogenic microbes. The implantation of foreign material into the body inevitably triggers a cellular response, generally assessed as aseptic inflammation. This reaction serves a protective function for the tissues and is aimed at promoting their regeneration. The intensity of inflammation and the duration of regenerative processes depend on the nature of the implanted material, its degree of biocompatibility, biological activity, and biodegradation [9,30].

A universal protective response of the macroorganism to a surgical suture thread is its effort to rapidly localize this traumatic factor by forming a focus of inflammation in the surrounding tissues, accompanied by corresponding vascular, biochemical, and cellular reactions, followed by the formation of a fibrous tissue capsule. The formation of a fibrous capsule around the thread is considered the most favorable outcome of this response, as in this case, the surgical suture material is effectively isolated from the macroorganism, which no longer reacts to it [9,10].

In pediatric surgical and urological practice, both resorbable and non-resorbable suture materials are used with their own advantages and disadvantages, and different authors may recommend one or the other depending on the specific surgical or urological pathology. Kubilay Sarikaya et al., in their study comparing resorbable and non-resorbable suture materials for the correction of congenital penile curvature, concluded that the use of resorbable sutures during surgery appears preferable due to a lower risk of granuloma formation, fibrous plaques, and reduced palpability of the created knots, issues that are more commonly associated with non-resorbable materials. These findings are consistent with data reported by other authors [39,40].

Irfan Wahyudi et al., in a meta-analysis examining the relationship between suture technique and suture material during ureteroplasty, specifically, comparing resorbable synthetic braided sutures with resorbable synthetic monofilament sutures, concluded that there was no significant difference in the overall complication rate; however, monofilament suture material exhibited faster absorption properties than braided sutures [46].

Some authors prefer monofilament suture materials due to their low tissue resistance and smooth penetration, whereas others recommend braided sutures because they are more resistant to the weakening effects of urine and are less prone to easy rupture [18,46].

W. Snodgrass and S. Yucel conducted a study comparing braided synthetic suture material with chromic catgut – a natural material – and found a reduction in the overall complication rate when using the synthetic material [43].

Several authors have analyzed early morphofunctional changes in the perivulnar region of the cecal mucosa in rabbits following suturing with polyglactin-910 and L-arginine-modified polycaprolactone. They concluded that the mean thickness of the cecal mucosa after colotomy increased with the use of both surgical threads; however, when L-arginine-modified polycaprolactone was used, the increase was smaller due to reduced hyperhydration of the connective tissue component of the mucosa, decreased leukocyte infiltration in the perivulnar area and accelerated reparative processes, making it suitable for practical use [5,36,37].

Stefan Gfroerer et al. conducted a comparison of fast-absorbing braided synthetic sutures of various commercial brands in adults and children who underwent elective skin surgeries, concluding that this type of suture material is effective, safe, and fast resorbable, allowing for excellent cosmetic outcomes [14].

Based on the bibliographic analysis, many researchers have highlighted the disadvantages of traditional suture materials, namely, catgut (reactogenicity, rapid loss of strength, knot loosening) and silk (reactogenicity, absorbent and cutting properties), which increase the likelihood of postoperative complications (wound dehiscence and infection, adhesion formation, etc.). Consequently, the results of using synthetic resorbable suture materials allow for the conclusion that they have a clear advantage over biological and natural resorbable threads, both in terms of minimal tissue reaction and their strength characteristics, as well as the complete elimination of degradation products from the body after fulfilling their tissue-joining function.

Current advantages of synthetic suture materials, as well as the potential for their further improvement, indicate significant prospects for expanding their use in surgical practice. Due to their high biocompatibility, stable mechanical properties, and the possibility of controlled resorption, synthetic threads provide reliable tissue approximation with minimal inflammatory response. This makes them promising for both routine surgical procedures and operations with an increased risk of infectious or postoperative complications. Moreover, the ongoing refinement of the chemical structure and physicomechanical characteristics of these threads opens new opportunities for the development of specialized suture materials tailored to specific clinical needs and tissue healing conditions [3,34].

Considering the promise of synthetic suture materials and their ability to provide controlled resorption with minimal tissue reaction, it is also important to examine the mechanisms of interaction between the body and the implanted material at the cellular level. Aseptic inflammation is understood as an immune system response aimed at removing a foreign substrate that, although possessing antigenic properties, does not actively resist the immune response, unlike pathogenic agents [22,44]. These properties are critically important for suture materials used in intra-abdominal surgical interventions.

In this context, a detailed analysis of various suture material samples was conducted to identify those exhibiting the most pronounced xenogenic properties, that is, the ability to interact with body tissues without provoking a significant inflammatory response. The findings of the analysis showed that the traditionally used catgut thread fully meets these criteria, as its biological base consists predominantly of collagen fibers from the submucosa of the sheep small intestine, providing high biocompatibility and natural resorption within tissues.

Conclusions

Based on the conducted literature review and analysis of up-to-date suture materials, the following conclusions can be drawn:

1. Contemporary surgery demands materials capable of providing reliable tissue approximation with minimal adverse reactions from the body. The biocompatibility of suture material is critically important, as it affects both the speed and completeness of wound healing and the likelihood of postoperative complications, including inflammatory and infectious processes.
2. Synthetic resorbable sutures demonstrate stable mechanical properties, controlled resorption, and low tissue reactivity. Their use ensures minimal inflammatory response, reduces the risk of suture infection, and promotes effective tissue regeneration. Compared with traditional natural materials (catgut and silk), synthetic threads offer greater predictability in terms of strength loss and functional duration within the body.
3. Although catgut and silk have been used in clinical practice for a long time, they have several limitations: rapid loss of strength, uneven knot behavior in moist

conditions, high Young's modulus, and the potential to provoke pronounced exudative or granulomatous tissue reactions. These factors increase the likelihood of postoperative complications, such as wound dehiscence, inflammation, and adhesion formation.

4. Aseptic inflammation following suture implantation is a natural protective tissue response that determines subsequent regeneration. An effective suture material should stimulate a localized and controlled reaction without forming excessive fibrous scarring or chronic inflammation.

5. Synthetic suture materials hold significant potential for further enhancement: improvements in chemical structure, braiding, and coating allow the development of specialized sutures tailored to specific clinical needs and tissue healing conditions. The use of modified polymers with antimicrobial properties opens new possibilities for ensuring reliable tissue approximation in surgical settings with a high risk of infectious complications.

6. Thus, synthetic suture materials represent an optimal choice for contemporary surgery due to their high biocompatibility, predictable mechanical properties, controlled resorption, and minimal tissue reaction. Their use contributes to improved surgical outcomes and a reduced incidence of postoperative complications.

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