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REVIEW

# Intra-abdominal hypertension and compartment syndrome after complex hernia repair

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## Abstract

**Purpose** Abdominal compartment syndrome (ACS) is a well-known concept after trauma surgery or after major abdominal surgery in critically ill patients. However, ACS as a complication after complex hernia repair is considered rare and supporting literature is scarce. As complexity in abdominal wall repair increases, with the introduction of new tools and advanced techniques, ACS incidence might rise and should be carefully considered when dealing with complex abdominal wall hernias. In this narrative review, a summary of the current literature will highlight several key features in the diagnosis and management of ACS in complex abdominal wall repair and discuss several treatment options during the different steps of complex AWR.

**Methods** We performed a literature search across PubMed using the search terms: "Abdominal Compartment syndrome," "Intra-abdominal pressure," "Complex abdominal hernia," and "Ventral hernia." Articles corresponding to these search terms were individually reviewed by primary author and selected on relevance.

**Conclusion** Intra-abdominal hypertension (IAH) and ACS require imperative attention and should be carefully considered when dealing with complex abdominal wall hernias, even without significant loss of domain. Development of a true abdominal compartment syndrome is relatively rare, but is a devastating complication and should be prevented at all cost. Current evidence on surgical treatment of ACS after hernia repair is scarce, but conservative management might be an option in the early phase and low grades of IAH. However, life-saving treatment by relaparotomy and open abdomen management should be initiated when ACS starts setting in.

**Keywords** Abdominal compartment syndrome · Quaternary · Complex hernia repair · Intra-abdominal pressure

## Introduction

Abdominal compartment syndrome (ACS) is a well-known concept after trauma surgery or after major abdominal surgery in critically ill patients. However, ACS as a complication after complex hernia repair is considered rare and supporting literature is scarce. As complexity in abdominal wall repair increases, with the introduction of new tools and advanced techniques, ACS incidence might rise and should be carefully considered when dealing with complex abdominal wall hernias. In this narrative review, a summary of the current literature will highlight several key features in the diagnosis and management of ACS in complex abdominal wall repair (AWR) and discuss several treatment options during the different steps of complex AWR.

The prevalence of ACS and intra-abdominal hypertension (IAH) has been increasingly recognized in patients admitted to the intensive care unit (ICU). Incidence differs vastly among literature; IAH and ACS have been reported as high as 65% and 3%, respectively, in patients admitted to the ICU. Especially patient suffering from acute pancreatitis, orthotopic liver transplantation and abdominal aorta surgery are at high risk of developing ACS. Mortality in IAH is associated with the grade (Grade I: 10–25%, Grade II: 15–45%, Grade III–IV: 50–60%), while ACS carries a reported mortality risk between 75 and 90% [1, 2].

ACS is diagnosed when there is a persistent intra-abdominal pressure (IAP) measurement of more than 20 mmHg, together with the presence or onset of organ dysfunction or failure. ACS is classified into four distinct categories based on the underlying pathology: primary, secondary, tertiary (or recurring), and quaternary abdominal compartment

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syndrome (QACS). Primary ACS is characterized by the development of increased pressure within the abdominal cavity due to injury or disease, such as abdominal aortic aneurysm repair or pancreatitis. Secondary ACS arises from extra-peritoneal or systemic conditions, such as severe sepsis in critically ill patients. Tertiary or recurrent ACS refers to patients who have previously been treated for primary or secondary ACS and are now experiencing a recurrence of ACS. Quaternary ACS, which was first introduced by Kirkpatrick et al., is considered ACS after (complex) abdominal wall repair [3]. QACS stands apart as it occurs in a distinct patient population. They typically do not have severe illness or injury and are expected to exhibit greater resilience against the detrimental effects of IAH/ACS [4].

To identify patients at risk for QACS development, several risk factors have been identified which contribute to and define the complexity of a hernia patient. Obesity is a known risk factor for post-operative surgical site infections (SSI) and increases the risk of respiratory insufficiency after repair [5, 6]. Furthermore, obesity leads to a higher resting intra-abdominal pressure and lowered abdominal compliance, which in turns leads to less accommodating capacity when herniated viscera are reintroduced [7]. A clear threshold for surgery has not yet been defined; however, a dose-dependent relation is seen [8]. Smoking (and COPD), has a similar effect as obesity, where it negatively impacts wound healing and morbidity and leads to a higher re-admission rate after surgery [8, 9]. As it affects patients pulmonary capacity, it is easy to understand that it leads to a higher rate of respiratory complications after extensive hernia repair and reduced abdominal compliance due to reduced reshaping capacity of the diaphragm [5, 7]. Smoking cessation 4 weeks prior to surgery is advised and can be checked by urine cotinine testing [10, 11].

When considering hernia characteristics, a recent Delphi consensus was published to define an incisional hernia as complex, this translating in surgical complexity and post-operative complication rate. A hernia width of > 10 cm, previous component separation, recurrences/previous repairs, and loss of domain (LOD) were considered contributing factors to hernia complexity. As expected, previous component separation and abdominal wall repairs will significantly affect abdominal compliance, and lead to stiffening of the abdominal wall [7]. LOD can be estimated by different methods reported by Tanaka [12] or Sabbagh [13]. A cut-off percentage could not be formulated, nor by a previous consensus meeting dedicated to LOD [14]. As with other types of ACS, excessive fluid resuscitation during prolonged surgery should be avoided.

## Pathophysiology

The abdominal cavity is a closed anatomical compartment with somewhat compliant walls, including the diaphragm and abdominal musculature. The IAP is dependent on both the volume inside the abdomen (intra-abdominal volume or IAV) and the flexibility of the abdominal wall (abdominal wall compliance or AWC). An increase in IAV can be caused by increased intraluminal (e.g., gastric distention due to severe ileus) or extraluminal volume (e.g., intra-abdominal abscess). Decreased AWC can be caused by, e.g., burns or previous abdominal wall repair (as indicated above) [2]. Therefore, when faced with an ACS, appropriate action should be taken depending on the provoking mechanism (e.g., gastric decompression through nasogastric tube, abscess drainage, or escharotomy). In complex hernia repair, prolonged herniation of visceral content into a non-anatomic cavity will lead to disuse atrophy, lateralization, retraction, and thickening of the abdominal wall musculature, hereby leading to loss of muscle elasticity and increased rigidity of the abdominal wall, lowering its compliance [15, 16]. Additionally, the herniation will cause dysfunction and descent of the diaphragm [16]. Therefore, with sudden reintroduction of the hernia content during repair, this will massively increase the IAV and deplete the already "injured" compensatory mechanisms [5].

Blaser et al. identified 3 phases during an increase of IAV, as expected during (complex) hernia repair [7]. Initially, the reshaping phase leads to configurational changes of the abdominal wall and thus a minimal change in IAP. This is followed by a stretching phase in which elastic elongation of the abdominal wall and diaphragmatic tissue accommodates the further increase in volume but only leads to a modest increase in IAP. Both phases are compensatory phases and can account for the fact that during 'simple' hernia repairs, no or minimal change in IAP is observed [3, 7]. Finally, a pressure phase is reached, in which all compensatory mechanisms are depleted and a small increase in volume leads to a significant increase in pressure (the characteristic pressure–volume relationship found in a confined space).

The normal range of IAP is 0–7 mmHg, although it can reach levels as high as 12–14 mmHg in those who are severely obese [2, 17]. The measurement of IAP is often conducted via a urinary Foley catheter; however, it can also be done by nasogastric tubes or abdominal drains [18]. To accurately determine IAP readings and identify patients who may develop IAH or ACS, it is necessary to do regular assessments at 4–6 h intervals. The World Society of the Abdominal Compartment Syndrome (WSACS) has published a standardized trans-bladder method for measurement and monitoring in their 2013 consensus statement. This method involves measuring IAP at the end of expiration while in a supine position, guaranteeing complete relaxation of the abdominal muscles [7, 10]. During abdominal wall closure, it is recommended to initiate intraoperative IAP measurement to assess potential exacerbation and elevated pressure.

IAH is diagnosed when the IAP exceeds 12 mmHg. Originally established as an observational threshold, research has demonstrated that IAP as low as 12 mmHg can lead to renal injury, liver damage, decreased splanchnic outflow, and is linked to higher rates of illness and death in critically sick patients [20]. The WSACS has classified IAH into four grades based on different IAP levels. Grade I corresponds to an IAP of 12–15 mmHg, Grade II corresponds to an IAP of 16–20 mmHg, Grade III corresponds to an IAP of 21–25 mmHg, and Grade IV corresponds to an IAP greater than 25 mmHg [19].

ACS is diagnosed when there is a persistent IAP measurement of more than 20 mmHg, together with the presence or onset of organ dysfunction or failure. When examining organ failure in ACS, kidney failure is commonly mentioned, but hepatic, adrenal, gastrointestinal, and respiratory failure are also linked to ACS [21].

In general, every complex hernia repair might lead to a rise in IAP, but whether this is clinically relevant remains questioned. Petro et al. showed that in 50 patients undergoing ventral hernia repair with myofascial release, the incidence of any grade of IAH was 92%. In 46 patients, the IAP significantly decreased post-operative day 1, with no increased morbidity, nor relevant acute kidney injury, coining this transient increase in IAP permissible hypertension [4]. Espinosa-de-los-Monteros et al. saw a similar trend, with 30% of patients ($N=43$) experiencing IAH, but without developing ACS [22]. Others observed the same, with or without using component separation [6, 17–19]. Therefore, one could argue that standardized IAP measurement after hernia repair is not clinically necessary.

However, while seemingly clinically benign, studies have shown a negative clinical impact of Grade I and Grade II IAH. A study conducted by Mohan et al. demonstrated that in a pig model, microscopic small bowel necrosis occurred even at lower grades of IAH [24]. Other studies have demonstrated that mild IAH can have detrimental effects on the microcirculation and tissue oxygenation in critically ill patients, resulting in higher rates of morbidity and sequelae [20]. This phenomenon has also been observed following significant abdominal surgery and could therefore be extended to complex abdominal wall repair [25]. Moreover, obstructing the microcirculation hinders the healing of connective tissues such as fascia, which could result in the reappearance of the condition at an earlier stage (i.e., hernia recurrence) [21]. Schachtrupp et al. demonstrated that intermittent IAH also has an impact on the tension of sutures. They determined that IAH leads to a notable decrease in suture tension along the suture line, resulting in fascial dehiscence [26]. Consequently, the significance of standardized IAP measurement continues to be beneficial, while its precise role in clinical decision making remains somewhat uncertain.

Through the diaphragm, pressure in both abdominal and thoracic compartment are connected. Therefore, changes in IAP will inevitably affect respiratory function. Gaidukov et al. demonstrated that an increase in IAP after ventral hernia repair resulted in a decline in the elimination of carbon dioxide ($CO_2$) and subsequently a decrease in the oxygen levels in the arteries, indicating a decline in respiratory function [27]. In case of complex hernias, Schlosser et al. showed that after repair of defects more than 200 cm or a LOD index of more than 0.5 (according to the Tanaka-method), there was a notable rise in the risk for respiratory insufficiency (defined as the requirement for non-invasive positive airway pressure support for more than 1 day) [5]. To avoid QACS development after hernia repair, several studies have investigated whether pre-operative mechanical ventilation parameters could be used as a guide for intensified post-operative management (i.e., prolonged intubation after surgery). Blatnik et al. showed that an increase in plateau pressure of more than 6 cm $H_2O$ is related to severe post-operative respiratory complications and need for reintubation [28]. Two other case reports, reporting on the occurrence of ACS following hernia repair, also saw a significant rise in peak airway pressure after hernia repair [23, 24].

## Reducing risks of ACS

### Pre-operative measures

**Pre-optimization and prehabilitation** As already mentioned above, several modifiable risk factors have been identified which increase post-operative morbidity and QACS risk and should be properly addressed before surgery [29]. No specific threshold for BMI has been set; however, as escalating weight increases the risk of SSI, patients should be encouraged to lose weight before hernia repair. Several studies have shown the beneficial effect of a rigorous low-caloric diet prior to surgery; however, the result highly depends on the motivation and dedication of the patient [8, 29]. When faced with morbid obesity, a staged repair, encompassing bariatric surgery before hernia repair could be considered. Evidence favors this staged approach, when looking at wound morbidity and recurrences in the morbidly obese, but this again depends on the willingness of the patient to undergo an additional procedure [29]. Smoking cessation at least 4 weeks before surgery is advised and can be checked through urine cotinine testing prior to surgery (cut-off value: 200 ng/ml) [8]. Intensive support during smoking cessation via telephone follow-up shows better results with regard to the complete smoking cessation, but is limited by feasibility and reimbursement [29]. Diabetes has been shown to be a risk factor for morbidity after ventral hernia repair, and proper glycemic control should be achieved before surgery. Some reports consider a HbA1c of less than 7% a cut-off value for surgery [10, 30]; however, this was not included in the recent EHS guidelines [29].

**Botulinum toxin A (BTA)** BTA is a neurotoxin produced by the bacterium *Clostridium botulinum*, which has been shown to have a variety of therapeutic uses through its inhibitory effect on presynaptic cholinergic nerve terminals [31]. Injections applied to the lateral wall of the abdomen promote temporary flaccid paralysis which, in theory, helps in drawing the midline together for a more tension-free suture line [32].

Onabotulinumtoxin A (Botox®, Allergan, Dublin, Ireland) or abobotulinumtoxin A (Dysport®, IPSEN, Boulogne-Billancourt, France) is commonly used in different dosages, i.e., 200–300 IU and 500 IU, respectively. The amount and location of injections sites differ between both products and depend on center protocol. The same can be said for the indication for BTA usage [33]. Some authors advocate the injection of all layers, while others started to refrain from injecting the transversus abdominis muscle. Due to the theoretical concern that injecting the transversus abdominis decreases truncal stability prior to repair, the recent reports of no additional midline gain comparing 2- to 3-layer injection and when a surgical transversus abdominis release (TAR) is planned. As BTA is still currently off-label use, 2-layer injection might also decrease patient's financial burden [10, 34].

BTA is generally injected about 4–6 weeks preoperatively under ultrasound, EMG or CT guidance [34]. It has a very low complication rate, encompassing primarily a sense of bloating, a weak cough, back pain or pain in general, and superficial bruising at the site of the injections [33]. Two recent systematic reviews showed a mean lengthening of the lateral muscles of around 4 cm [32, 34] and a high fascial closure rate [34].

**Progressive pneumoperitoneum** Progressive pneumoperitoneum (PPP) was first described by Goni Moreno in 1947. PPP acts as a pneumatic tissue expander and attempts to restore lost abdominal cavity space to enable the safe reintroduction of herniated viscera [35]. Moreover, it induces progressive respiratory rehabilitation, by increasing the diaphragmatic tone and efficiency of the other respiratory muscles, to prepare the patient for the increased IAP after viscera reintroduction [36]. Adhesion release [35], as well as muscle lengthening, has also been attributed to PPP [37]. Indications for PPP can differ between centers; however, LOD of at least 20–25% and a hernia width of minimum 10 cm are most frequently noted [33, 38]. PPP has shown promising results in treating complex hernias when looking at fascial closure rate [33, 35, 39], and shows a low reported incidence of ACS after repair.

Several different protocols have been described for PPP, encompassing different insufflation techniques and regimens, as shown by the recent review by Martínez-Hoed et al. [35]. However, its widespread use has been impeded by its labor-intensive nature, as well as its high complication rate when compared to BTA. The review by Martínez-Hoed et al. showed an overall complication rate of 13%, most of them only minor, without need for intervention [35], but it can be as high as 60% [38]. Shoulder or neck pain, as well as abdominal discomfort and subcutaneous emphysema, is most frequently reported and does not need any intervention, but respiratory failure, ACS, or visceral injury during catheter placement have also been reported [10, 36, 38, 40]. PPP furthermore increases the chance of thromboembolic events, and therefore, several papers advise the routine use of venous thromboembolism prophylaxis [10, 35, 38]. Bearing the above in mind, PPP is generally contraindicated for patients who are at a high risk for developing venous thromboembolism, elderly patients, or those with cardiopulmonary disease.

When faced with a complex hernia, both BTA and PPP might be combined [33, 41]. *Tashkandi* et al. showed in their series that adding BTA to PPP might not lead to an increased abdominal volume, but it lowered the post-operative surgical site occurrences [39]. No benefit regarding lateral wall muscle length has been noted [34]. BTA seems the most important tool to obtain lateral wall muscle lengthening, while PPP might be better indicated in cases with significant loss of domain. Further studies are needed to critically appraise the outcomes and indications for the combination of both techniques.

## Intraoperative measures

### Component separation techniques (CST, anterior and posterior)

To achieve midline fascial re-approximation in large ventral hernia, Ramirez et al. popularized the external oblique release in 1990 [42]. The term "anterior component separation" refers to the combination of the release of the external oblique aponeurosis with a conventional retromuscular repair. This approach necessitates the development of extensive subcutaneous flaps, resulting in a significant rise in wound-related problems, exceeding 60% [43]. In order to address this, various adaptation have been created, such as the endoscopic anterior CST or the epigastric perforator vessel sparing anterior CST [44, 45]. Posterior component separation, also known as TAR, was introduced by Novitsky et al. [46]. This technique gained rapid popularity since it seamlessly builds upon the retromuscular plane. The mesh is positioned in the retromuscular location, allowing for a generous mesh overlap and eliminating the need for extensive subcutaneous dissection. This technique shows low rates of surgical site events [47]. Performing a component separation during complicated hernia repair increases the likelihood of achieving a tension-free midline repair [48] and also increases the capacity of the abdomen by altering the abdominal dimensions and abdominal compliance, resulting in a reduction in intra-abdominal pressure after hernia repair [16]. Both the surgical procedures themselves, as well as the indication for both approaches, are beyond the scope of this article.

### Fascial traction

Ventral herniation will lead to fascial retraction and muscle shortening. To counteract this, e.g., during open abdomen management, several devices and techniques have been developed to achieve fascial closure [49, 50]. This concept was extrapolated to more complex abdominal wall reconstruction by Eucker et al., applying vertical traction to the fascial edges for a prolonged period of time, showing good lengthening of the lateral wall [51]. The initial experimental technique necessitated a stable retractor system, together with eight towel clamps and eight elastic reins. Based on this experimental setup, the same group was the first to introduce the Fasciotens© system (fasciotens GmbH, Essen, Germany), which is currently available for purchase. This system allows for the application of a horizontal force prior to surgical midline closure [52]. Thus far, there is a dearth of extensive and comparative studies employing this method in the context of complicated ventral hernia. In a prospective observational trail conducted by Niebuhr et al., it was shown that the application of 30 min of intraoperative traction resulted in an average increase in fascial length of 9.8 cm. This increase is similar to the effects seen in both forms of component separation [48, 53]. None of the patients included in this study exhibited QACS, as determined by IAP measurement. Additional data are required to determine the efficacy of fascial traction in abdominal wall repair, as well as the necessity for reimbursement of this costly device.

### Post-operative measures

During fascial closure, surgeons should be aware of QACS with perceived tight fascial closure, or with changes in mechanical ventilation measures. Following their pilot-study [28], Blatnik et al. adapted their post-operative care and left all patients with a change in plateau pressure greater than or equal to 6 cm H2O intubated for an additional 24 h. Patients with extreme changes in plateau pressure (≥ 9 cm $H_2O$) were additionally given a paralytic agent in addition to remaining intubated for 24–48 h. Using this approach the same group reported that no patients, extubated under these criteria, suffered from ACS, despite a high prevalence of IAH post-operatively [4]. Chandra et al. employed a threshold of 30 cm $H_2O$ for peak airway pressure during surgery to determine if intubation needed to be prolonged, along with a subjective assessment of a tightly closed surgical incision. Although a significant proportion (64%) of patients experienced prolonged intubation, none of the patients who were subsequently extubated developed IAH or ACS [54].

Patients with a high index of suspicion should be monitored intensively with regular interval IAP measurements. As low levels of IAH (Grades I–II) seem to be transient in nature [4, 22] and might not be clinically relevant, these patients can be managed by conservatively. Higher levels of IAH should be addressed more aggressively. As IAP depends on both IAV and AWC, any intervention should be targeted against one or both. This encompasses reducing intraluminal volume (e.g., nasogastric tube for gastric decompression, rectal cannula, etc.), reducing extraluminal volume (e.g., drainage of ascites, etc.), and improving abdominal wall compliance (e.g., prolonged sedation, removal of tight binders, etc.) [2]. Several papers show good results with conservative measures, with the largest series described by Chandra et al. [54, 55].

When the above fails, or with the onset of ACS, surgical decompression should be considered. However, after complex abdominal wall reconstruction, a relaparotomy would nullify the previous repair, while the different dissected anatomical planes will often not be reusable. Whether a full laparostomy should be performed, converting the planned hernia repair to an open abdomen, or whether additional surgical steps can be taken to decrease the IAP, without compromising the repair, is still unclear.

## Management of ACS

Literature about ACS treatment in hernia repair is scarce, largely being case reports. Oliver-Allen et al. described a case of ACS after combined anterior CST and an onlay small pore synthetic mesh. After partial release of the onlay mesh, pressure resolved [56]. Mavrodin et al. converted a classic Rives-Stoppa repair to a bridged repair, in order to reduce IAP [57]. However, converting to a bridged repair increases the risk of recurrence significantly [58]. Other theoretical possibilities are relaxing Gibson incisions of the anterior fascia, adding any form of component separation or adding an anterior CST after a previous posterior CST [59] and vice versa; however, literature about this is still lacking.

When insufficient, a full laparostomy should be performed and a temporal abdominal closure is used. After the initial resuscitation and clear organ recuperation, efforts should be made to close the abdomen as soon as possible. Definitive fascial closure (DFC) should be achieved within 10–14 days [50], as the complication rate increases after 7 days [60]. Previously applied temporary static closure techniques with either a "Bogota Bag" or a synthetic or biological bridging mesh have been abandoned due to lowered DFC rate, higher rate of enteroatmospheric fistula formation and large incisional hernia formation [50, 61]. The current treatment guidelines advocate the use of dynamic closure techniques, with fascial traction using either a mesh or specific traction system (e.g., ABRA©-system), in association with a negative pressure wound therapy (e.g., Abthera© system—3M Company, St Paul, USA), thus achieving a DFC rate of around 75% [49, 50, 61, 62]. In an effort to reduce the incidence of incisional hernia after open abdomen (OA) in the acute care setting, some authors have proposed to integrate a strip of mesh during initial OA treatment, leaving this in place after closure [63, 64]. Whether this would suffice as repair after QACS remains unknown.

In order to further increase the DFC rate, and to lower midline tension to improve fascial closure, BTA can be administered after laparostomy, if not already done pre-operatively [65]. A recent systematic review by Luton et al. shows promising results (DFC rate 90.7% vs 66%); however, additional studies are necessary to confirm these results, due to a large heterogeneity between studies [66].

Furthermore, to speed up DFC, some authors have advocated the use of continuous vertical traction (Fasciotens©—fasciotens GmbH, Essen, Germany) during the early post-laparostomy phase (rather than horizontal traction during the initial procedure), in combination with negative pressure wound therapy. In the assumption that vertical traction can be applied earlier than the above mentioned dynamic closure techniques, due to increased intra-abdominal volume (i.e., in case of persistent visceral edema), this would limit fascial retraction and allow for early DFC [52, 67, 68]. However, due to the limited number of studies and included patients, its superiority over other techniques remains elusive, especially when considering the increased costs related to the device.

## Conclusion

IAH and ACS require imperative attention and should be carefully considered when dealing with complex abdominal wall hernias, even without significant loss of domain. A clear understanding of the pathophysiology of ACS and the role of IAP measurement is essential.

In order to prevent, rather than to cure, a thorough risk assessment should be made pre-operatively. Pre-operative optimization, through patient counseling in case of obesity or smoking and using BTA or/and PPP administration, is important. Therefore, when faced with a complex incisional hernia, surgeons should not only rely on their surgical skillset but also optimize their patients and set clear goals regarding known modifiable risk factors.

Adequate intraoperative evaluation of the bladder pressure could early identify patients at risk after definitive repair. Intraoperative continuous monitoring of the ventilatory parameters might also help in deciding which patient potentially deserve prolonged intubation and sedation in order to avoid progression to QACS.

Current evidence on the surgical treatment of QACS is scarce, but conservative management might be an option in the early phase and low grades of IAH. Nevertheless, once abdominal compartment syndrome (ACS) develops, it is crucial to promptly undertake life-saving treatment through relaparotomy and open abdomen care, even if it means sacrificing the prior repair.

## Declarations

**Conflict of interest** The authors have no related conflicts of interest to declare.

**Ethical approval** For this type of study ethical approval is not required.

**Human and animal rights** This article does not contain any studies with human participants performed by any of the authors.

**Informed consent** For this type of study formal consent is not required.

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