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An Updated Review on the Diaphragmatic Hernia in Bovines

Vandana Sangwan[1], Ashwani Kumar[1]

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ABSTRACT

Diaphragmatic hernia is a common surgical condition in buffaloes but is occasionally recorded in cattle. A high hospital occurrence of diaphragmatic hernia in buffaloes raises a concern and a thought on the aetiology, as it affects the socio-economic status of the farmer. Scientific literature published to date could not establish any definitive aetiology of diaphragmatic hernia in bovines. However, it is also definitive that diaphragmatic hernia is not a congenital condition as the symptoms start appearing not before one year of age. Some anatomical factors listed specifically for buffaloes may also add to the aetiology other than the foreign body, advanced stage of pregnancy, or recent calving. Being a slow-progressing and non-infectious condition, early diagnostic and prognostic factors based on clinical, imaging and haemato-biochemical parameters and the selection of cases for surgical intervention are important. The article reviews the literature, when it was first time diagnosed, its global incidence, etiological factors and advancement in the diagnostic modalities, anaesthetic and surgical treatment methods, productive and reproductive outcomes and future directions.

Key words: Aetiology, Buffalo, Cow, Diaphragmatic hernia, Prognosis, Reticulum, Surgery.

Diaphragmatic hernia (DH) is a surgical condition in which a tear in the diaphragm leads to the protrusion of various abdominal organs from cranial abdominal cavity, primarily the reticulum, into the thoracic cavity. DH in bovines, mainly buffaloes, is primarily reported from India and Egypt whereas sporadic reports are from Canada. Cattle and buffaloes are the major milk producing animals in India and thus are important from the socio-economic point of view. It would be worth writing a comprehensive review on the various aspects of this important disease condition of bovines.

This review congregates the hitherto scattered literature on the diaphragmatic hernia in cattle and buffaloes since its first reporting. Besides, it highlights the gaps in the existing research and presents a multitude of possibilities to bovine clinicians and researchers to answer most needed questions like aetiology, prognostic factors and innovations in its treatment.

Organs herniated

The organs positioned in the vicinity to the diaphragm such as the reticulum (invariably herniated), liver, spleen (Prasad *et al*., 1977; Singh *et al*., 1977; Prasad *et al*., 1979; Krishnamurthy *et al*., 1980; Deshpande *et al*., 1981), abomasum (Prasad *et al*., 1979) and sometimes even intestines (Horney and Cote, 1961) herniate into the chest cavity. As there can be involvement of multiple organ(s) but reticulum is invariably involved, debate on the nomenclature of the condition as 'reticular diaphragmatic hernia' (Deshpande *et al*., 1977; Mohindroo *et al*., 2007) or only 'diaphragmatic hernia' has been reported.

History and aetiology

The DH may be an acquired or congenital condition, but the one encountered in buffaloes appears to be acquired as the clinical signs are not reported by birth but at the sub-adult or adult stage. Reports of acquired DH in bovine are rarely reported (Singh *et al*., 1980a). The youngest age reported for DH in buffaloes is one year. Respiratory distress, as reported in cow calves suffering from congenital DH (Horney and Cote, 1961; Deshpande *et al*., 1977) is rarely reported in DH buffaloes or if reported, is mostly associated with aspiration due to regurgitation/bloat. Respiratory distress has been reported as one of the common clinical signs in congenital DH (Trout *et al*., 1967). DH in adult bovines is a slow progression condition with the development of strong fibrinous adhesions (Abdelaal *et al*., 2014) between the hernia ring and the reticulum (Deshpande *et al* 1981), plugging the diaphragmatic tear tightly to ensure no air leak and hence no respiratory distress.

Congenital DH in cattle calves is occasionally reported and at an early age {Horney and Cote, 1961; Troutt *et al*., 1967; Lewis 1974; Hunter, 1980; Mitsuo *et al*., 1989; Bellavance *et al*., 2010 (due to dystocia handling), with successful surgical correction in a few cases (Troutt *et al*., 1967; Bellavance *et al*., 2010). Recently, Sahil *et al*. (2023) investigated the role of COUP-TF II and GATA-4 genes in the diaphragmatic tissues of healthy and DH buffaloes with differences in the COUP-TF II gene. Besides, exploring such genes, investigation is required to compare the status of these genes between cows and buffaloes or other species.

[1]Department of Veterinary Surgery and Radiology, College of Veterinary Science, Guru Angad Dev Veterinary and Animal Sciences University, Ludhiana-141 004, Punjab, India.

Corresponding Author: Ashwani Kumar, Department of Veterinary Surgery and Radiology, College of Veterinary Science, Guru Angad Dev Veterinary and Animal Sciences University, Ludhiana-141 004, Punjab, India. Email: drashwanikumar@rediffmail.com

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Acquired DH in water buffaloes has a hospital incidence of as high as 40% (Dhablania *et al*., 1971; Doere and Jahagirdar, 1971; Singh *et al*., 1977; Deshpande *et al*., 1981). DH is rarely reported in cows/cattle (Dollar, 1895; Milne, 1951; Hall, 1963; Deshpande *et al*., 1977; Saini *et al*., 2001; Saini *et al*., 2007; Sharma *et al*., 2024). However, a latest report showed an equal occurrence of DH in cattle and buffaloes (Suryawanshi *et al*. 2023). DH in a buffalo has been earliest documented in an MVSc thesis from Bombay Veterinary College, India (Deshpande, 1965), where it was an incidental finding during laparo-rumenotmy. The scientific documentation of DH in buffaloes appeared in 1969 from India (Kohli and Kumar, 1969; Naik and Mehendale, 1969; Iyer, 1969).

Two major predisposing aetiologies associated with the occurrence of DH in buffaloes are advance stage of pregnancy (Hutchkins *et al*., 1957; Dhablania *et al*., 1971) and presence of sharp metallic foreign bodies (Hutchkins *et al*., 1957; Krishnamurthy *et al*., 1985a; Singh *et al*., 1989). Absence of sharp metallic foreign body (Deore and Jehagirdar, 1971; William *et al*., 2003) or their presence in only 50-70% of DH buffaloes (Singh *et al*., 1977; Deshpande *et al*., 1977; Prasad *et al*., 1977; Krishnamurthy *et al*., 1985a; Saini *et al*., 2000, Saini *et al*., 2001) has also been reported. Similarly, 50% of DH incidence in non-pregnant heifers/ buffaloes (Singh *et al*., 1980a; Saini *et al*., 2000; Saini *et al*., 2001), or in early gestation (Singh *et al*., 1977; Deshpande *et al*., 1977), or incidence in ox/bullocks (Done and Drew, 1972; Deshpande *et al*., 1977) and buffalo bulls (Angelo and Joshi, 1969; Sobti *et al*., 1989) also nullified the hypothesis of traumatic reticulitis and pregnancy as the primary aetiological factors. Only 26% of bovines presented with sharp metallic foreign bodies developed DH (Krishnamurthy *et al*., 1985a), while remaining either developed pericarditis or lung abscesses or peritonitis alone.

DH is commonly reported on the right side to cardia, followed by the central and the least to the left side in buffaloes (Singh *et al*., 1980a; Deshpande *et al*., 1981), though more commonly on the left side in cattle (Tubbs, 1953; Troutt *et al*., 1967; Muradwar *et al*., 1986). This raises the question of the anatomical position of the reticulum in buffaloes in comparison to cows. Incidence of DH is rarely reported from organized private or institutional dairy farms, which may be due to better maintenance or no practice of wallowing (Singh *et al*., 2006), but also be that the buffaloes are culled if not productive and the condition remained undiagnosed.

Another aetiology described for DH in buffaloes is elevated intra-abdominal pressure during straining, impaction, or severe bloat (Singh *et al*., 1980a). There is a relative difference between the intra-peritoneal and the intra-pleural pressure gradients in non-pregnant buffaloes (8.16±0.81cm of H_2O) as compared to cows (5.50±0.82 cm of H_2O). However, these values were almost similar in pregnant and non-pregnant buffaloes (Venkataravanappa and Krishnamurthy, 1984a). Thus, greater tension is exerted on the buffalo diaphragm during inspiration and expiration, thus leading to more stress and predisposing it to rupture in comparison to cows.

The water buffaloes reported here, are tolerant to heat stresses and as the name suggests are happy to wallow in ponds during hot months. It has been hypothesized that wallowing may also increase the intra-abdominal pressure abruptly and if the diaphragm is inherently weak it can act as an exciting factor for the rupture of the diaphragm (Singh *et al*., 2006). However, to nullify it, wallowing is not a common practice in most of the parts of India and buffaloes are kept stall fed, but still many DH cases are reported.

Diaphragm structure and composition

The tendino-muscular junction on the right ventral side, a few centimeters below the foramen ovale (Deshpande *et al*., 1981) is the most common site for DH in buffaloes. It was hypothesized that the innate weakness of the diaphragm at this site in buffaloes is the reason for its rupture. To study the difference in the diaphragm of buffaloes and cows, a few histological and biochemical studies have also been done. The conclusions reported from these studies supporting the fact that the right ventromedial musculo-tendinous portion is prone to occurrence of DH in buffaloes are:

- At the musculotendinous junction, the tendinous fibres extend only into the indentations of the sarcolemma and do not penetrate the muscles resulting in a weak junction (Krishnamurthy *et al*., 1983).
- The right ventromedial tendinous zone of the buffalo diaphragm is thinner (0.85mm) than the left ventromedial zone (1.35mm, thickest) (Krishnamurthy *et al*., 1985a).
- The peri-cardio-phrenic vessels responsible for the vascular supply to the central tendinous area of the cattle diaphragm are missing in buffaloes and the caudal phrenic vessels are not able to fully compensate for this deficiency (Sharma *et al*., 1981; Krishnamurthy *et al*., 1985 b) resulting in a weaker central tendinous area in buffaloes.
- The golgi tendon organs that function as the pressure receptors are absent in buffalo diaphragm at the musculo-tendinous junction (Roy, 1980). The tendinous, costal and sternal parts are all thick and the strain on the junctional zone makes it more prone to rupture (Roy and Das, 1983).
- The percentage of dry matter elastin content of sternal and costal parts of the diaphragm is non-significantly less in buffaloes compared to cattle. Even the left ventral tendinous portion has much higher dry matter elastin content compared to the right side in buffaloes, which was otherwise much higher and equal on both sides in cattle. In the right tendinous part, the mean elastin content in buffaloes is only 50 percent to that of cattle (Venkataravanappa and Krishnamurthy, 1984b). However, the dry matter myosin content was higher in buffaloes in these regions compared to cattle.

- The hydroxyproline content of ventral and right tendinous parts of buffalo diaphragm is comparatively lesser than that in cow (Venkataravanappa and Krishnamurthy 1984b).

Clinical signs

The common clinical signs of DH are recurrent bloat, partial anorexia, hard black faeces or diarrhoea (Athar *et al*., 2010), drop in milk yield (Dhablania *et al*., 1971; Kumar *et al*., 1980), dehydration and rough coat (Singh *et al*., 1977). The presence of recurrent tympani, with frothy bloat, is pathognomonic of the disease condition and is believed to be due to occasional entrapment of reticulo-omasal groove in the hernia defect and/or deviation of cardia due to involvement of oesophagus (Deshpande *et al*., 1981) leading to impaired eructation and hence bloat. However, history of absence or one time bloat has also been reported (Athar *et al*., 2010). The frothy bloat could be due to churning of feed in the herniation and mixing of gas accumulated in the rumen due to impaired eructation. Relieving of gas through trocar or needle is non-responsive and the buffalo may regurgitate, especially when exposed to high environmental temperature. With bloat, the rumen and reticulum are hyper-motile. Presence of brisket oedema has also been reported in a few advance cases of DH (Athar *et al*., 2010), though no pericardial effusions were found on ultrasonography, which could be due to pressure of reticulum on heart or caudal vena cava (Deshpande *et al*., 1981).

Elevated rectal temperature is a rare feature of DH in buffaloes (Singh *et al*., 1977) and if reported is mostly due to hyperthermia from environment temperature. Absence of complete anorexia makes the condition chronic and debilitating, though otherwise the behaviour of buffalo is hyperactive. The behaviour of sick cattle on the other hand is observed to be dull due to fast reduction in haemoglobin compared to buffalo with the same number of illness days. Development of abomasal ulcers may be related to the passing of hard black faeces by the bovine. High yielding bovines have also been reported to be prone to DH (Tubbs, 1953; Hutchkins *et al*., 1957; De Moor *et al*., 1969; Dhablania *et al*., 1971, Prasad *et al*., 1977).

Auscultation

Clinical examination of lower chest using stethoscope while listening to the splashing sound of reticulum in the chest and the muffled heart sound in a few (Singh *et al*., 1977; Ghanshym *et al*., 2020) has been recommended under field conditions for the diagnosis of DH as radiography is not available. However, auscultation may not be useful when severe adhesions are there and reticular motility is absent (Kumar *et al*., 1980), or when some other organ is herniated along with the reticulum (Prasad *et al*., 1979). Other than reticular organs, if herniated, are difficult to diagnose on auscultation or radiography and require exploratory laparo-rumenotomy (Prasad *et al*., 1979).

Radiography

Earlier the radiography of large animals was restricted to limbs, head and neck due to the non-availability of high powered X-ray machines. But with the improvement in the technology of X-ray machines, the radiography of thorax and reticular region was made possible (Ilijas and Rapic, 1972).

The first X-ray machine with a 200mA unit for the projection of thorax and abdomen in large animals especially buffaloes was made available in the Veterinary College, Hisar, Haryana, in India, in 1970. Vig and Tyagi (1973) compared reticulography (200-350 g barium sulphate) and plueurography (35% diodone solution, 20-30 ml) as contrast radiographic procedures in experimentally induced diaphragmatic hernia in buffaloes.

The reticulography was recommended in right recumbent lateral positions, with a 200mA x-ray unit (Vig and Tyagi, 1973, Bhargawa and Tyagi, 1975) using 200mAs, 100KVp and 76 inches (190 cm) FFD (film-focal distance) (Bhargawa and Tyagi, 1975, Kumar *et al*., 1980). In doubtful cases, oral contrast reticulography with 1 kg Barium sulphate was made after 15-20 min (Kumar *et al*., 1980).

Foreign bodies were defined as potential (sharp metallic) and non-potential (iron fillings, rings, chains, spoon, keys, nuts, bolts, silver and gold ornaments, etc.) and potential were considered important for the causation of DH, while non-potential were mostly non-traumatic with exceptions like penetrating metallic spoon (Kohli *et al*., 1982).

The early radiographic features described for DH using plain radiography were presence of soft tissue mass in the thoracic cavity with foamy appearance and having continuity with the density of rumen and reticulum. The heart, lung and diaphragmatic shadows were not differentiable (Bhargava and Tyagi, 1975). With contrast radiography using barium, the reticulum and diaphragm were better visualised with the break in the continuity of diaphragm and cranial displacement of heart visible (Bhargava and Tyagi, 1975).

In 1977, the radiographic features were slightly modified with the absence of 'clear Diaphragmatic line' to be suspected for DH and was subjected to contrast reticulography while a distinct break in diaphragm line or presence of reticular patch cranial to diaphragm (with or without foreign body) and displacement or partial or complete over-shadowing of the heart to be confirmative for DH (Deshpande *et al*., 1977; Kumar *et al*., 1980). The presence of honeycomb appearance of herniated reticulum in few bovines has been related to presence of gas in it (Farrow, 1999), otherwise, in others, a soft tissue sac like opacity is visible, due to its contents.

Radiography for the diagnosis of DH in bovines has been recommended in right (Kumar *et al*., 1980) or left (Misk and Samieka, 2001) lateral recumbency (using 14′ 17″ or 432×356mm film and a stationary grid below the cassette). In standing position, the heavy humeral musculature of buffaloes does not allow the forelimbs to be extended forward and the olecranon overlaps the ventral diaphragm region, making the diagnosis of DH difficult (Kumar *et al*., 1980; Kohli *et al*., 1982; Misk and Samieka, 2001).

The cassette is placed behind the elbow to cover the area caudal to 5th intercostal space (ICS) and ventrally including sternum (Kumar *et al*., 1980). The machine settings were kept at 100cm FFD, 80-120 KVp and 90-100 mAs (Kumar *et al*., 1980) compared to what had been used earlier (Bhargawa and Tyagi, 1975) and later with better machine technologies the settings reduced to 50–60 mAs, 90-100 KVP and 90-110 cm FFD (Athar *et al*., 2010). The diaphragm line can be clear if there is gas in herniated reticulum. Apart from visualization of honey comb opacity cranial to diaphragm, presence of non-potential foreign bodies with or without sac visualization in chest is also considered confirmatory for DH as the non-potential foreign bodies cannot penetrate the diaphragm without being herniated along with the sac.

Most of the limitations of radiography described in the literature are overcome today with the availability of better X-ray technologies such as Computed and Digital Radiography. Presence of chest growth, cystic opacity and cardiac/phrenic/lung abscess is still the radiographic differentials for DH if no non-potential foreign body or iron/ sand dust is visible cranial to diaphragm. Casting of bovine for reticulography of DH is also a major limitation in bovines with bloat, advanced stage of pregnancy, regurgitation or pericarditis. Since, buffaloes with pericarditis less commonly show the typical clinical sign of brisket edema (Kumar *et al*., 2012; Sangwan *et al*., 2018) and are at the risk when casted for reticulography.

Ultrasonography

Successful diagnosis of reticular diaphragmatic hernias using ultrasonography was first-time reported in buffaloes (Mohindroo *et al*., 2007) and cows (Saini *et al*., 2007). This diagnostic technique was considered a boon in the history of DH as it was done on non-sedated, standing bovines and thus, was safe for advanced pregnant and/or bloated bovine which was otherwise risky for radiographic examination in a recumbent position. Ultrasonography was recommended in real time B-mode with a 3·5 MHz microconvex (Mohindroo *et al*., 2007; Saini *et al*., 2007) or 2-5 MHz multi-frequency curvilinear transducer (Kumar and Saini, 2011; Kumar *et al*., 2017). The criterion for diagnosis was the visualization of characteristic biphasic reticular motility of reticulum at 4th and 5th ICS (i.e in the chest). As the herniated reticulum is usually on the right side between the heart and right thoracic wall, it is possible to scan the thick echogenic band of about 1 cm, corresponding to the reticular wall from the right 4th ICS, shadowing the heart. However, during the reticular contractions, it is possible to scan the heart from the right 4th ICS. And when conducting, an ultrasonographic examination from the left side, the reticular wall will be seen medial to the heart (Kumar *et al*., 2017, Aneja *et al*., 2022). However, the honeycomb structure of the reticulum and the foreign bodies could not be seen ultrasonographically (Mohindroo *et al*., 2007).

With the advent of ultrasonography, further studies focussed on the comparative diagnosis of DH using ultrasonography and radiography and concluded ultrasonography to be accurate than radiography in both cows and buffaloes. However, a false positive diagnosis of DH cannot be ruled out using USG (Athar *et al*., 2010). Another study concluded that the cupula of diaphragm in healthy cows is slightly cranial in comparison to healthy buffaloes (Makhdoomi *et al*., 2018) and thus the reticulum can be visualized one ICS cranial to that is seen in healthy non-pregnant buffaloes. It may move further with advance stage of pregnancy, so the ultrasonographic visibility of the reticular wall and motility at the 5th ICS as a diagnostic criterion for reticular diaphragmatic hernia should be interpreted with caution concerning the species and pregnancy status of the animal; however, is confirmatory (with no clause) at 4th ICS (Kumar and Saini, 2011). Another study has reported congenital variation in the number of sternebrae in cow and buffalo calves and thus may affect the ICS position of various organs in adult stage (Verma *et al*., 2023). Morphometry of DH reticulum from different windows has also been reported (Aneja *et al*., 2022). The Doppler USG of major vessels close to heart like, jugular, carotid and cranial epigastric has been reported with certain variation in DH buffaloes as compared to healthy (Sangwan *et al*., 2015; Sangwan *et al*., 2019). Apart from diagnostic utility, ultrasonography can play a vital role in the prognostic assessment of a DH-affected bovine.

Ultrasonography too had certain limitations including, the false negative in the diagnosis of small DH and contrast radiography would be more reliable (Kumar and Saini, 2012) in such a situation. On ultrasonography, visualization of foreign body is not possible which otherwise is required as these are to be removed during rumenotomy. For USG and to approach the 4th ICS, the corresponding side forelimb need to be pulled forward using a rope or hand, which is sometimes difficult in certain bovines. In extensive herniation, the diagnosis for DH can be made using the cranial thoracic approach with the forelimb not stretched and transducer placed cranial to forelimb and lateral to brisket directed into the chest (Kumar *et al*., 2017).

Hemato-biochemistry

Many studies were conducted to document hemato-biochemical findings in bovines suffering from DH. Significantly elevated total leucocytes with neutrophilia and total protein is a consistent finding on bovines positive for DH (Kaur and Singh, 1994; Rose *et al*., 2009; Abdelaal *et al*., 2014; Attia, 2016; Ghanshym *et al*., 2020) irrespective to the presence of foreign body, which was correlated to the destruction of lymphocytes due to stress (Jain, 1986) tissue damage and suppuration at the site of injury (Kaur and Singh, 1994). The SGOT, Creatinine Kinase and Serum Creatinine (Ghanshym *et al*., 2020, Suryawanshi *et al*. 2023) are significantly high and SGPT to be significantly low in DH buffaloes as compared to normal (Kaur and Singh, 1994; Rose *et al*., 2009). DH may cause reduced serum total bilirubin, AST, BUN, creatinine glucose, lactate and fbrinogen in buffaloes (Hussain *et al*., 2021). The erythrocytic indices show macrocytic normochromic anaemia in DH, while it was macrocytic hypochromic in foreign body syndrome (Kaur and Singh, 1994), which was correlated to the deficiency of folic acid and cobalt (Jain, 1986).

Surgery

The diaphragmatic herniorrhaphy (DHy) requires major surgical intervention done in dorsal recumbency under general anaesthesia and the cost, time and manpower involved are significant. In India, bovine are not the primary food animal and the owner mostly go for the surgical treatment. The government-funded Indian institutes provide subsidized surgical treatment facilities for the farmers, therefore, a lot of efforts and research is being focused on the development of safer anaesthetic protocols and surgical approaches for DHy in bovines.

In late 1960's many cases of DH were diagnosed in buffaloes and a treatment requirement emerged. The experimental repair was made successful in buffalo calves (Vig and Tyagi, 1974; Singh, 1974), though it was different from the clinically presented adult. The adult clinical buffaloes had strong adhesions with no controlled respiratory technique for positive pressure ventilation and had a large rumen putting pressure on the diaphragm while suturing hernial defect in dorsal recumbency.

The procedure of DHy was started in 2 stages as is even followed today, with certain alterations. In earlier days, the rumen was partially emptied through left flank rumenotomy in standing position and the foreign bodies from the reticulum were removed in the 1st stage while in the 2nd stage the hernia ring was sutured in dorsal recumbency under general anaesthesia. The 2nd stage was done after 4-14 days of stage one and the bovine were called 24 hrs off-feed and off-water for it (Singh *et al*., 1977). The herniorrhaphy procedure was done using a crescent incision through a post xiphoid approach (Singh *et al*., 1977; Prasad *et al*., 1979; Singh *et al*., 1980b). The surgical gloves were not used during surgery as they used to slip off inside while operating. The braided silk no. 4 was used for suturing the diaphragm in continuous lock stitch pattern (Singh *et al*., 1977). Earlier attempt to repair the diaphragm was with interrupted mattress sutures (Vig and Tyagi, 1974; Singh, 1974) or synthetic patches (Vig and Tyagi, 1974) and was not found satisfactory compared to the continuous lock stitch using no. 4 braided silk (due to its high tensile strength) (Singh *et al*., 1977). Now-a-days, no. 2 braided silk is used, made double by making a loop, but this is less ideal for suturing of diaphragm in a continuous lock stitch pattern as two threads may intermingle with each other and is likely to break, thus complicating the procedure. The commercial availability of at least 300 cm single strand long suture material no. 4 or 5 with swaged on heavy taper cutting needle No. 1 will be highly useful, but, limited marketing and commercial non-viability of such unusual suture materials is of concern for pharmaceutical companies.

Transthoracic approach through resection of 20-30 cm of sixth rib (Krishnamurthy *et al*., 1980) or 7th rib (Gahlot *et al*., 1989) under general anaesthesia or local standing anaesthesia (Singh *et al*., 1996) has also been described from right side with satisfaction except where; there was close adherence of herniated reticulum with lungs or pericardium (Nigam *et al*., 1980).

The linea alba incisions and right or left para-costal incisions have also been tried for DHy in bovines (Singh *et al*., 2002). Though, the post-xiphoid semilunar incision provides the maximum working space but it is associated with incising abdominal muscles and thus excessive bleeding. Besides, it requires careful placement of sutures because of excessive muscle tension leading to incisional hernia (Kumar *et al*., 2012). In the linea alba approach, in dorsal recumbency, the bleeding is minimal, suturing is easy but the working space is less. This approach is sometimes also called as 'blood less surgery'. The linea alba approach is currently recommended for DHy and other peri-reticular lesions (Kumar *et al*., 2018) in cows and buffaloes.

Usually bovines have single hernia ring, however, two or more hernial rings have also been reported (Deshpande *et al*., 1977) and repaired successfully (Singh *et al*., 1979; Krishnamurthy *et al*., 1983; Saini *et al*., 2016). But, in such cases, limited diaphragmatic tissue leads to more tension and thus may predispose to post-surgical recurrence and pain. Such cases may be considered ideal for the use of prosthetic mesh. It will be necessary to oppose the hernial defect before using prosthetic mesh so that there is no air leakage through the mesh fenestrations. However, the authors never realised the need to use prosthesis grafts in clinical practice. The magnitude of recurrence of DH following herniorrhaphy in bovines need to be investigated to justify the need of adjuvants/prosthetic meshes in DHy. Earlier, autologous skin graft (Ramakumar *et al*., 1979), polypropylene and nylon mesh (Troutt *et al*., 1967; William *et al*., 2003) have also been tried to close the rent.

The size of the hernia ring may vary from 6 to 25 cm with the ring mostly 8cm above the xiphoid (Singh *et al*., 1977; Deshpande *et al*., 1981) and adhesions with pericardium, pleura, lungs and thoracic wall and fibrous tracts having metallic foreign bodies (60%) and reticular abscesses (20%) (Deshpande *et al*., 1981).

Surgery for DHy is not generally advised in advanced pregnant bovines (more than 9 month pregnant) as the mature fetus fills the abdominal cavity that reduces working space for the dissection of adhesions and suturing of the diaphragmatic rent (Singh *et al*., 2006).

A single stage approach to DHy in buffaloes has been described under xylazine sedation and local anaesthesia and in dorsal position. The rumenotomy for evacuation of ingesta and foreign body was done using McLintock's rubber ring through post xiphoid semilunar incision followed by DHy (Ghanshym *et al*., 2020).

The pleura is usually intact in DH; however, the herniating organ (usually reticulum) develops variable degree of adhesions, as per the chronicity, with the hernial ring and the thoracic structures such as parietal pleura. In buffaloes, generally the adhesions are so firm and extensive that these need to be severed with scissors to make the reticulum free and to pull it back into the abdominal cavity for DHy. This process, sometimes results in tear in the reticulum, pleura, lungs, liver and pericardium. The whole procedure is done through palpation as the visibility is not possible due to its anatomic position and surgical approach. Careful dissection of adhesions close to the herniated organ can prevent damage to the pleura. Use of rigid/flexible endoscope may aid in visualizing the herniated organ(s), diaphragmatic rent, extent of adhesions and neighbouring structures and thus avoiding major complications and improving the outcomes.

As pleural cavity (parietal and visceral pleura) has negative pressure (vacuum), so parietal pleural is in close association with the lung surface (visceral pleura). After the herniated organ is replaced into the abdominal cavity, the space remaining in the thoracic cavity (between the diaphragm and parietal pleura) is well defined up till the parietal pleura is intact. Pleura can rupture grossly or with minor damage with needle piercing and former is easy to diagnose, as the other thoracic structures will be palpable (lungs and heart). However, in the event of the minor tear in pleura, the air moves into the pleural sac resulting in pneumothorax and the potential space remaining in the thoracic cavity is less defined due to sagging of parietal pleura. Pleural rupture is considered one of the serious intraoperative complication and poor prognostic indicator and such cases require intensive care during and after surgery (Singh *et al*., 2023). Lungs are overinflated by positive pressure ventilation before closing the last suture and free air in the pleural cavity is suctioned out to manage the developing pneumothorax associated with pleural rupture (Singh *et al*., 1977).

Anaesthetic protocols

Several innovations occurred in the anaesthetic protocols for DHy in bovines. Use of soda bicarb in the ruminal fluid and inj. Prednisolone (anti-oxidant) were recommended in DH bovines prior to anaesthesia for surgical repair. The 6% chloral hydrate was used as a pre-anaesthetic and the induction and maintenance was done with 5% Thiopentone sodium in earlier days (Singh *et al*., 1977). However, with large doses of chloral hydrate, oxygen extraction ratio of the tissue was critically low (Mirakhur *et al*., 1980) and a reduced dose of choral hydrate till the nystagmus appeared, was found helpful (Mirakhur *et al*., 1983). A 25 mm endotracheal tube (non-cuffed and locally made with a rubber pipe) was used and was attached to respirators (manual of positive pressure ventilators). The respirators were used to create negative pressure in the thoracic cavity by hyper ventilation just before the tightening of last lock stitch (Singh *et al*., 1977). Subsequently, air from abdomen was removed as it helped in early restoration of spontaneous breathing during recovery (Singh *et al*., 2006). Since, there are adhesions hanging in the thoracic cavity and there was formation of multiple air pockets in between the pleura and diaphragm, all the air was difficult to be removed by suction and the hyperventilation technique was more effective, even today. The assisted respiration was continued for 1.5-2 hrs and complete recovery would take 2-3 hrs after surgery (Singh *et al*., 1977). A need for good muscle relaxant, endotracheal tube with cuff and positive pressure ventilation for the repair of DH arise (Deshpande *et al*., 1977).

With the availability of inhalant anaesthesia, halothane was used for the maintenance during surgery along with intermittent positive pressure ventilation (IPPV), but it caused severe hypotension (Peshin *et al*., 1986) and A-V dissociation in several animals and was not recommended safe for DH repair in supine position (Gahlawat *et al*., 1986). Use of halothane also highlighted the problem of regurgitation during surgery (Saini *et al*., 2000). Other combinations like triflupromarine and low doses of choral hydrate (6%) followed by induction and maintenance with thiopentone (5%) (Krishnamuthy *et al*., 1998), diazepam-thiopentone and chloral hydrate, haloperidol-thiopentone- halothane were used (Saini *et al*., 2001). The total induction dose of the barbiturate varied from 2 g to 10 g in adult buffaloes (Krishnamuthy *et al*., 1998).

Later, the anaesthetic protocol of diazepam or midazolam as pre-anaesthetic and thiopentone as the induction agent and maintenance with halothane (Saini *et al*., 2007; Singh *et al*., 2013) was followed. Midazolam was considered better than diazepam for electrolyte balance. To prevent respiratory acidosis, mechanical ventilation was recommended throughout the surgical procedure (Singh *et al*., 2013). The use of isoflurane and sevoflurane for maintenance and premedication with Glycopyrolate-xylazine-butorphanol and thiopentone has also been reported in buffaloes, with faster recovery with sevoflurane (Choudhary *et al*., 2017).

The DHy had also been tried successfully using chloral hydrate sedation and local anaesthesia (2% lignocaine hydrochloride) through ventral approach in buffaloes and crossbred cows (Marudwar *et al*., 1986; Usturge and Bhokre, 1989; Singh *et al*., 1996; William *et al*., 2003, Talekar *et al*., 2018). The successful repair of DH under local anaesthesia is possible when the ring is not extensive and the pleura is intact, so that the bovine is breathing spontaneously throughout, but if during breaking of the adhesions, the pleura (Saini *et al*., 2001) or mediastinum (Prasad *et al*., 1980) ruptures, need for positive pressure ventilation arises (Singh *et al*., 2023). Half reticular resection has also been successfully advised to avoid adhesion breakage (Fazili *et al*., 1994; Fazili *et al*., 1998), but the excitatory and inhibitory receptors of vagus nerve responsible for reticulo-ruminal motility are located densely in the medial wall of the reticulum, the reticulo-ruminal fold, the reticular groove and the central part of the dorsal ruminal sac (Leek, 1969), which if resected will hinder the function. Reticular resection, may not be practically feasible as well later, the reticulum also need to be sutured and chances of infection increases many fold.

Post-operative care

Post-operative care with isotonic fluid therapy (NSS, DNS, RL), antibiotics and analgesics along with 3 days of hydrocortisone (Singh *et al*., 1977), B Complex, liver extract, stomachic preparations and yeast tablets (Behl *et al*., 1997; Singh, 1997; Tagra *et al*., 2001) was recommended in DHy bovines.

Chronic starvation in cases of DH leads to electrolyte imbalance and further to hypokalaemia and hypochloraemia, leading to either abomasal atony or achalasia of pylorus i.e. caudal functional disorder (Behl *et al*., 1997; Singh, 1997; Tagra *et al*., 2001). To correct this imbalance, 5 litres of hypertonic saline (2.7% NaCl) with 6-8g of KC1, intravenously, was used (Behl *et al*., 1997; Singh, 1997; Tagra *et al*., 2001) on the first or subsequent days of surgery.

Use of Vitamin E as an antioxidant during DHy has been recommended (Bisla *et al*., 2002) and also had no effect in another study (Sahu *et al*., 2002). Further studies are recommended to justify the rational incorporation of the antioxidants in the treatment protocols.

Prognostic factors and outcome

The earlier studies (Singh *et al*., 1977) reported an uncomplicated recovery in 68.42% of bovines (13/19) with the major poor prognostic reason being the brisket oedema (3/19). However, the long term reproductive and productive outcome was 100% (Singh *et al*., 1977, Kumar *et al*., 2012). A success rate of up to 80% was reported (Singh *et al*., 1977; Prasad *et al*., 1977) in almost 200 bovines with DHy.

Twice reoccurrence of DH in a buffalo has been reported (Ramakumar *et al*., 1979). The second time ring was next to the first one repaired. This second-time re-occurrence was repaired using an autologous skin graft of full thickness from a free skin region, which was successful up to 8-month follow-up.

The poor prognostic factors for DHy in buffaloes are; advanced stage of pregnancy, regurgitation, brisket oedema, anaemia (low haemoglobin of less than 7 g/dl), highly alkaline rumen pH of 9-9.5, foreign bodies, regurgitation during anaesthesia, cardiac or respiratory complications and severe adhesions with pleura and pericardium causing respiratory and cardiac compromise along with longer operative time (Saini *et al*., 2000). Singh *et al*. (2023) correlated the status of the pleural integrity with the survival of buffaloes undergoing DH. Majority report did not highlight assessment of pleural integrity because it is difficult to diagnose minor tear/needle puncture of the parietal pleura intraoperatively. However, in the opinion of the authors' pleural integrity is one the major prognostic factors responsible for intraoperative mortality or morbidity in DH.

Favourable prognostic factors for DHy in buffaloes are; ruminal pH of 7-8, good haemoglobin, least fibrous tracts and absence of reticular abscess/nodule, minimum regurgitation and complications during anaesthesia, non-pregnancy or early pregnancy and absence of other accompanying disease (Saini *et al*., 2001; Sahu *et al*., 2003).

FUTURE DIRECTIONS

Despite much published literature on the DH in bovines; no definitive ethology could be identified which a still is worrying in formulating strategies to control this economically important condition. Establishment of genetic causes may help in screening of herd for identification of susceptible animals and their culling. Higher occurrence of DH in buffaloes as compared to cattle suggest that different genetic makeup or body conformation of these species might be playing an important role in the etio-pathogenesis of DH; however, there is lack of scientific documentation on this aspect. Besides, there is a scope for modifying the surgical technique; use of endoscope during surgery, designing of surgical instruments to facilitate dissection of tough adhesions and effective suturing of the diaphragm for favourable surgical outcomes.

CONCLUSION

Diaphragmatic hernia is an economically important surgical condition, most commonly reported in buffaloes and occasionally in cows. No definitive aetiology is reported and is a major hurdle in the prevention of the condition. Advancements in the diagnostic, anaesthetic and surgical techniques have improved the outcome. The review highlighted the gaps in the DH research on bovines and will serve a useful document to guide researchers working on it.

Conflict of interest

All authors declare that they have no conflicts of interest.

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