

## The Subdural Myth: Space or Place?

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### Abstract

The term "Subdural" is commonly used loosely to describe any item below the Dura Mater, but when considering the mechanics of Shaken Baby Syndrome it is necessary to keep to the original definition of a space between the Dura Mater and the Arachnoid mater.

In 1991, a survey of literature relating to the structure of the meninges found that 32 out of 42 articles stated that a fluid filled space (the "Subdural Space") existed between the Dura Mater and the Arachnoid mater which allowed the brain to slide relative to the skull. This is still the case in Shaken Baby Literature.

With the coming of Electron Microscopy it was found that there was no subdural space. The position was filled by a structure formed by a specialized region of the dura. Commonly known as the Dural Border Layer, it is merged below with the outer aspect of the Arachnoid. Although it is strongly attached to the main dura above and the Arachnoid below it is internally weak and easily torn along the middle during handling producing a "subdural" space. It is suggested that the "Dural Border Layer" be recognized as an independent structure, the "Subdura".

The structure of the Subdura suggests that its function is stress relief. It allows variation of brain proportions, during maturation and aging, to take place over a period of weeks or months, without producing distorting stress in the brain tissue.

The Shaken Baby documents declare that subdural haemorrhages are caused by shearing forces as the brain moves. They also say that visible contusions are unusual. Since the Subdura joins the Arachnoid to the Dura the brain cannot slide unless all the subduras are torn, creating a massive contusion. Hence it appears that the Shaken Baby Syndrome cannot involve brain movement.

**Keywords:** Subdural; Dural border layer; Shaken baby; Electron microscopy

### Introduction

#### Background up to 1991

Shaken Baby Syndrome is a disorder commonly believed to result from a carer under stress from an infant's incessant crying, losing their temper and shaking an infant, causing the brain to slide around in the skull. This sliding is said to take place across a fluid filled space situated between the Dura Mater and Arachnoid Mater. The ease with which this could happen depends on the properties of this space, known as the subdural space. Evidence of shaking is considered to be the presence of three symptoms, known as the triad. These are Subdural Hemorrhages, Retinal Hemorrhages, and changed mental status. This article concentrates on the former, Subdural Hemorrhages. The term "Subdural" is commonly used to describe any item below the Dura Mater but here it is used in the original, more specific sense, of lying between the Dura and the Arachnoid.

In the 1970s, when the SBS concept was created, most paediatricians thought that a fluid containing space existed just below the dura, known as a subdural space (Figure 1).

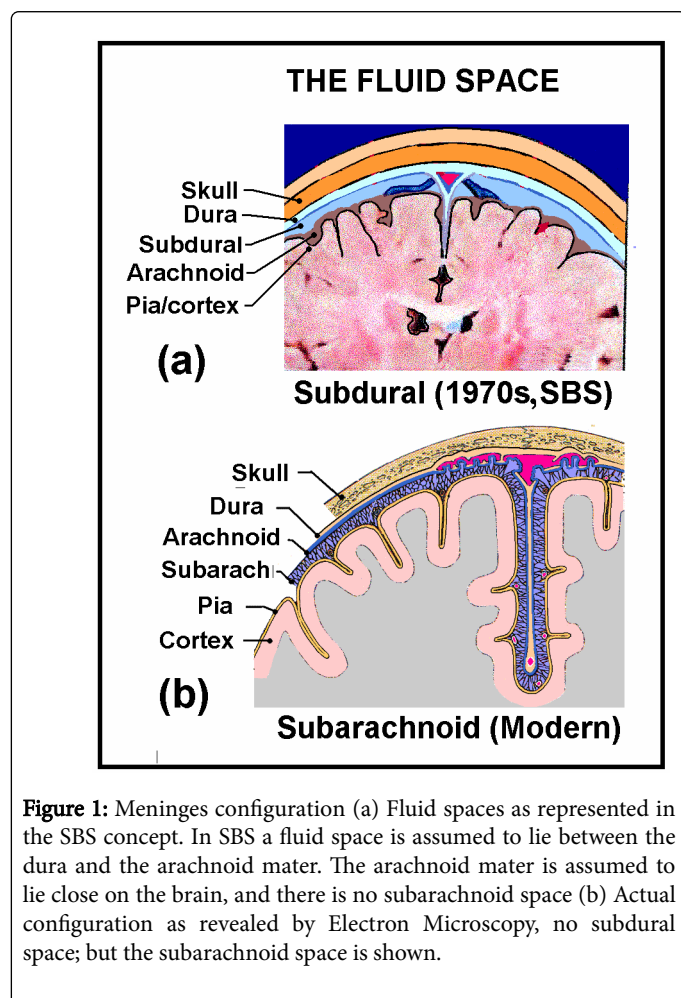
In 1991 Haines surveyed the literature on the subdural space [1,2]. He found 42 publications concerning, or descriptions of, the subdural space from contemporary (1991) textbooks or atlases in gross anatomy, histology, and neuroscience [1]. He quotes Romanes [3] that "*The arachnoid is separated from the dura by a bursa-like, capillary space (the subdural space) containing a film of fluid. This forms a sliding plane where movement is possible*".

Some argued that this was only a potential space like that surrounding the lungs defined as: - "*A true potential space is one that may be created without disrupting the normal structure/functional integrity of the tissues involved in creation of the space*" [4]. Summarizing his findings, Haines says: - "*A representative survey of the extant teaching literature... reveals that the majority (36/42) ... state categorically that a subdural space is present between the arachnoid and dura. In a minority of this sample (6/42) the probable existence of a subdural space is clearly qualified or specifically denied*" [4].

So in 1991 there was still general agreement that a subdural space, or at least a potential space, existed. This is still the case in SBS publications, the origins of Figure 1 were published in 2004 [1].

### Electron microscope developments (1991 onwards)

With the arrival of electron microscopy it was found that there was no subdural space but there was a subarachnoid space. The postulated Subdural Space was not empty. It was filled with a layer of unique tissue derived from the inner aspect of the Dura, and was firmly attached to the outer (barrier) layer of the arachnoid. Under stress this layer would split leaving parts still attached to the Dura and other bits still attached to the arachnoid.



**Figure 1:** Meninges configuration (a) Fluid spaces as represented in the SBS concept. In SBS a fluid space is assumed to lie between the dura and the arachnoid mater. The arachnoid mater is assumed to lie close on the brain, and there is no subarachnoid space (b) Actual configuration as revealed by Electron Microscopy, no subdural space; but the subarachnoid space is shown.

This discovery led to a period of intense research into this new structure, leading to a wide range of descriptive terms. Some describe its position; others seem to describe its nature. Haines [4] lists “dural border cells”, “subdural cells”, “subdural mesothelium”, “light cells”, “neurothelium”, “intermediate cellular layer”, “subdural compartment”, “arachnoid outermost zone”, “arachnoid superficial zone”. Each is relevant to the particular study in which it appears. Part of the reason for the neglect of this dura-arachnoid junction structure is probably the variety of names that have been devised to identify it. Although this region is considered to be within the dura its structure is essentially different, Figure 2. There are no tight junctions linking fibrocytes as in the rest of the Dura, in fact large open spaces, filled with granular material are found between them [4,5]. When, during handling, a split appeared it was always through this layer. While the description Dural Border Layer accurately describes it from a pathological point of view, it does not recognise its mechanical

function. It is a structural element in its own right. It is suggested that from an engineering point of view “Subdura” is used with the same status as “Dura”, Arachnoid, Pia etc.

Haines summarized the findings relating to the structure of the meninges in a diagram [4] on which Figure 2 is based. The outer layer of the Dura is attached to the inside of the skull. It is composed of fibroblasts and plentiful extracellular collagen fibrils. These reinforce this layer. It contains nerves and blood vessels [4]. Under that lies the meningeal dura with more fibroblasts and less collagen. Next inwards is the Dural Border Layer, here referred to as the entity “Subdura”. Unlike the outer dura and meningeal dura the Subdura is completely free of collagen. Its fibroblasts are widely spaced and of irregular shape which produces extensive extracellular spaces filled with an amorphous, non-filamentous material. Whereas cells in the Dura above are held together by various forms of junction, Nabeshima [5] reported “no tight junctions of any type are found between dural border (Subdura) cells”. The inner surface of the Subdura is continuous with, and hence attached to, the Arachnoid Barrier layer. Cells in this arachnoid barrier layer are extensively attached to each other by desmosomes, tight junctions and gap junctions. Tight junctions are so numerous that they make this layer virtually water-tight. This also renders the Arachnoid a very tough layer [4].

When Nabeshima et al. [5] attempted to examine the dural border layer (Subdura) [5] they found that “The exact site of the subdural space was not immediately apparent in those preparations where the dura and arachnoid did not separate during dissection. When the dura did separate from the arachnoid, the split was within the layer of dural border (Subdura) cells [5]”.

The proportions in Figure 2 have been adjusted for clarity. Orlin et al. show in their Figure 1, a photo micrographic montage of a section through pig cerebral meninges [6]. They give thickness of the dura as varying between 100 and 300  $\mu\text{m}$  whereas the thickness of the Subdura (their “Subdural Compartment”) is only about 5  $\mu\text{m}$ , as is the arachnoid barrier layer. There is no gap between the Subdura and the arachnoid barrier. In their figure the Subarachnoid space is about 60  $\mu\text{m}$  across at the position they sampled.

### The weak subdura structure

Whereas most of the dura is toughened by copious collagen fibres, the lower boundary (known as the dural border layer, DBL (Subdura)) is devoid of collagen. Thus there is a sandwich of Dura, DBL (Subdura), and Arachnoid. The Dura is reinforced with collagen and cells in the Arachnoid Barrier are held tightly together with tight junctions. In contrast there are no tight junctions holding the subdural fibroblasts together and no extracellular collagen. If sufficient stress is applied, the DBL (Subdura) soft filling is torn apart (Figure 2 left-hand side). Remnants of the DBL (Subdura) are then found on the Dura and Arachnoid [2].

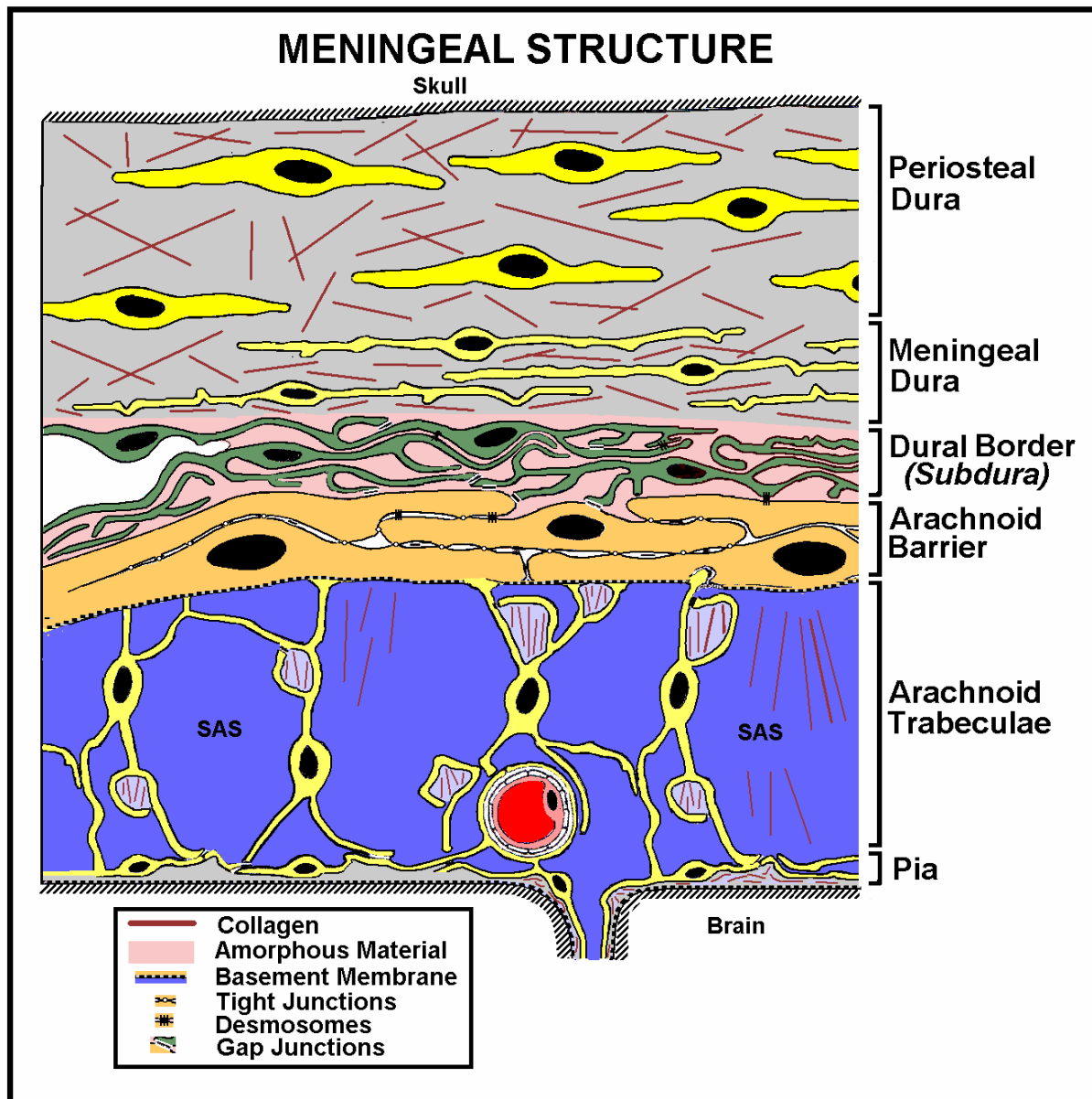
### Discussion

#### Subdura function hypothesis

Electron Microscopy shows such detail, from various authors, e.g. whether cell interconnections are tight junctions, Gap junctions, or desmosomes etc, there can be no doubt that other related features are genuine. At first sight, it seems curious that a mechanically weak layer should have evolved in such a critical position. Orlin et al. [6] hypothesized that the function of the Subdura is to match up changes

in the proportions of the brain and skull, such as are caused by cerebral development, or by shrinkage with aging [6]. (An example might be the expansion of the cerebral cortex in late pregnancy) The lack of

intercellular junctions in the Subdura allows fibrocytes to slide over each other.



**Figure 2:** The Meningeal Structure as revealed by Electron Microscopes [4]. Collagen is present in the periosteal and meningeal dura and in the folds of trabecular cells. The Dural Border Cell layer (Subdura) has no extracellular collagen, few cell junctions, enlarged extracellular spaces, no basement membrane, and fibroblasts that are distinct from those of the outer portions of the Dura. The arachnoid barrier cell layer has essentially no extracellular space, numerous cell junctions, more plump appearing cells, and a comparatively continuous basement membrane on its surface toward the SAS. Note the continuity of cell layers from the arachnoid to the Dura (no intervening space).

Though the mechanical nature of the granular material filling the space between fibrocytes is unknown, this structure suggests the Subdura has a plastic nature. If the brain were tightly attached to the skull the neurons would be subject to strain during differential brain growth e.g. Cortex versus brain base. During skull movements the plastic Subdura would provide strong support, but during growth its plastic nature would allow it to grow slowly to match the new brain

shape to the current brain inner contours. This would be an internal translational movement which would not require the breaking of the breaking of any previous fibrocyte bonds to fibrocytes in the main dura or arachnoid. Movement would be taken up by sliding of fibrocytes within the Subdura.

### Clinical significance

Without the subdural space the Brain cannot move unless the Arachnoid is torn from the Dura. Such a tear is a form of contusion, but contusions are said to be rare in SBS. The only way that the brain could move would be if all the Subdura connections were torn. The brain would then appear as one great bloody contusion. So there is no opportunity for sliding to take place between the Dura and the Arachnoid as required by the current version of the Shaken Baby hypothesis.

### Terminology

The current multiplicity of nomenclature for this region has arisen based on the appearance of its tissue, but functionally its structure differs so much from that of the rest of the dura that it deserves to be treated as a separate entity, the Subdura, like the Dura, Arachnoid, and Pia etc.

### Conclusion

As Schachenmayr and Friede [7] stated, their results clearly demonstrate that *“the outermost arachnoid and the innermost dura are tightly attached to each other in humans. This fact compels one to abandon the classic concept of subdural space”*. One is forced to agree with Haines who concluded that:- *“The appearance of the so-called subdural space is the result of tissue damage and is not due to the*

*expansion of a patent (or temporarily obliterated) pre-existing space. Consequently, this space is neither “actual” nor “potential”; it is in fact, non-existent in the normal situation..... The so-called subdural hematomas are actually dural border, (Subdura), hematomas”* [2]. Haines suggested that the term “spatium subdurale” be dropped from Nomina Anatomica *“because there is no evidence to support the view that it is a legitimate and naturally occurring space in the body”*[2].

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