

REVIEW ARTICLE

EVALUATION OF BI -SPECTRAL INDEX MONITOR IN CONTEXT OF LOW RESOURCE SETTINGS

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ABSTRACT

Arousal status of patient in correlation with anaesthetic effect is the vital consideration for an anaesthesiologist. Recent anaesthesia has proposed hi-tech solutions to deal with it. This review throws a light on practical and realistic approaches prior equipping the O.T. with sophisticated depth of anaesthesia monitors. This review includes information from literature on health technology assessment, Bi-spectral Index (BIS) and anaesthesia's current practice. It also portrays Indian and UK anaesthesiologist's perspectives on deployment of BIS and other similar modalities. It is expected that this article will help to save significant amount of overuse of healthcare resources in low resource settings by providing insight on ethical and economical aspects on use of such technology.

Key-words: Depth of Anaesthesia, Awareness, Bi-Spectral Index Monitor, Low –Resource Settings, Health Technology Assessment, Clinical Judgement.

INTRODUCTION

Anaesthesia is defined as reversible loss of all sensation modalities with or without reversible loss of consciousness. There are 4 basic aims of anaesthesia: 1) Analgesia 2) Amnesia 3) Areflexia 4) Muscle Relaxation. These are achieved by adequate dose and depth of anaesthesia. Thus, It is crucial factor to be monitored by anaesthesiologist. In earlier era of anaesthesiology, Guedel's classification was used to determine Depth of anaesthesia. But, advent of muscle relaxants and newer anaesthetic techniques resulted in abolition of most of Guedel's signs¹. This in turn made judgement of Depth of anaesthesia complex. Failure to maintain appropriate Depth of anaesthesia will result in awareness. Apart from conventional technique, Bi-spectral index monitors are introduced to monitor Depth of anaesthesia. However, being a new technology, it requires practical considerations before deployment. In case of low-resource settings, it is skeptical to invest money behind such expensive technology especially when there is scarcity of qualified and trained professionals.

Depth of Anaesthesia and awareness during anaesthesia:**Depth of anaesthesia:**

According to American Heritage Medical Dictionary, Depth of anaesthesia is defined² as "The degree to which the central nervous system is depressed by a general anaesthetic agent, depending on the potency of the anaesthetic and the concentration in which it is administered. Inability to deliver appropriate Depth of anaesthesia will lead to event so called as "awareness", which has serious psychological impacts regarding effectiveness of anaesthesia.

Awareness during anaesthesia:

Poor anaesthetic effect may result in development of intraoperative, perioperative, and/or post operative awareness. Intraoperative awareness is the unexpected recall of some or all the events occurred during anaesthesia. This in turn leads to patient having reluctant concerns on undergoing anaesthesia. The issue has been scientifically analysed by means of various clinical research studies to study the exact problems features. It has been shown by results of such studies that intraoperative awareness incidence is higher in children. Though not significantly prevalent, it occurs invariably in odds of 1 or 2 in 1000. Mostly the experience is not in form of pain. But, memory of intraoperative events is remembered in form of auditory recall or dreaming experience. However, There were several patients who reported severe pain recall due to awareness in these studies. Fewer Patients having awareness also reported post traumatic stress disorder, anxiety, nightmares and flashbacks like negative impacts.³

The exact cause of intra-operative awareness is not yet known. It may be due to improper dose titration and light anaesthesia. It may be accompanied by multiple factors like machine malfunction, misuse of anaesthetic machine and resistance to anaesthetics. Thus, it is difficult to have judgement of balance between anaesthetic dose and arousal status of patient. Considering awareness as the central nervous system (CNS) driven factor, autonomic signs are the most plausible determinants of depth of anaesthesia. It is the common practice to observe sign such as pulse, blood pressure, sweating and lacrimation.

However, it is obvious that the appropriateness of this observation depends on the intellectual ability of the anaesthesiologist. To enhance this ability with an objective solution, technologies with the concept of use of electroencephalogram (EEG), electromyogram (EMG) and nerve conduction velocity to determine consciousness level in patients are invented.

Bi-spectral Index (BIS) Monitor

BIS monitor is the recent technology based solution to measure depth of anaesthesia. It is the innovation by Aspect Medical Systems, MA. It quantifies the level of consciousness in form of an index called "Bi-spectral Index". This utilizes statistical signal processing approach to generate an index between 0 (indicating electrical zero) and 100 indicating (full conscious state).

Design and Function:

The apparatus is comprised of a sensor, a patient interface cable, Digital Signal Processing circuitry and controlling element (microprocessor/microcontroller), and a monitor. The BIS technology is also available as a module that can be integrated into other monitoring systems. The non-invasive sensor with self-adhesive backing is placed across patient's forehead and on temple's either left or right side using the alcohol. Wiping of alcohol will help reduce the impedance mismatch and will ensure for the quality signal acquisition. The sensor then sends raw EEG information through the cable to signal processing unit. After discretization of the signal in frequency domain, the signal is analysed using statistical approach known Bi-spectral analysis. This information will be fed in the look-up table created in microprocessor or micro-controller. Using this table, according to algorithm, corresponding value will be selected for the given input data. This corresponding value will be the Bi-spectral Index of the patient, a potential determinant of the patient level of consciousness.

Interpretation:

BIS reading near 100 indicates the state where a patient is awake and alert, while one with no brain activity will have a reading of 0 and ideally a flat EEG. It is the common observation that patients with BIS index > 70 are more likely to be conscious and able to follow commands and recall the procedure they're undergoing than those with lower readings.⁴ Similarly, patients with BIS index < 60 are found to be sedated. The typical range of BIS indices for effective sedation using general anaesthesia is assumed to be 40-60.⁴ Additionally, the real time plot of BIS value versus time, it is possible to determine the changes in level of consciousness in response to anaesthetic or other drug administration or external stimulation (development of evoked potentials in brain). This plot is also known as "BIS trend". The reliability of the value can be ensured using the Signal Quality Index (SQI), one channel EEG AND EMG displayed on monitor screen.

Stage of diffusion of BIS technology:

Being a recently introduced technology, its cost-effectiveness is yet to be proved by the manufacturers. Current available unit's cost as per literature available is around 5000 £ (8000 USD). It is counted excluding the sensor cost which is around 70 £. However, as per company profile data, it is shown to have installation of around 39,990 units worldwide⁵. Aspect Medical Systems (acquired by Covidien Healthcare) is the pioneer in BIS market with market cap of 28 billion USD per year. There are several studies performed and are in pipe line to establish the clinical effectiveness and cost-effectiveness analysis of this technology. But, there is no substantiality found out of them.

DATA COLLECTION

Literature review and interviews:

The topic relevant literature search was performed on Google search engine as well as PUBMED, SCIEDIRECT and Google SCHOLAR using key words like Depth of Anaesthesia and Bi-spectral Index monitoring, anaesthetist perceptions with BIS monitor, awareness and depth of anaesthesia. Bi-spectral index and awareness, BIS technology assessment, cost-effectiveness analysis of BIS monitor. There was no substantial information found on internet about BIS use in low resource settings and related issues. For such information, questionnaire based study was conducted and semi-structured interviews were conducted, responses to which are summarised further. The subject group for interviews was comprised of anaesthesiologists working in low resource settings, health economists and biomedical engineers. To avoid the bias in the review, no clue was given to the interviewee about previously available positive as well as negative results on BIS during the interview session. Studies selected for the review were also included both positive and negative aspects and outcomes so as to minimize implicit bias to least level.

Inferences from Clinical trials:

Clinical trials are performed to evaluate the safety, efficacy/effectiveness of superiority of BIS driven monitoring of depth of anaesthesia in humans. There are trials called "B-Aware Trial"⁶ and other randomized controlled trial in Beijing⁷, which have shown favourable results. But, there is mention about a prospective randomized trial, which was aimed at superiority evaluation of BIS over End tidal anaesthetic gas concentration based Depth of anaesthesia monitoring in New England Journal of Medicine, which revealed altogether contrary fact that the incidences of awareness in ETAG based anaesthesia was less than in that of BIS arm. On the other side, there is a systematic review⁸ which again contradicts former article conclusions. Another study – B-unaware trial⁹ showed no statistically significant difference in results in patients with BIS guided anaesthesia as compared to standard care in context of awareness. Additionally, "BAG-RECALL"¹⁰ trial results put the BIS recommendation on skepticism. However, it

can't be inferred that no statistical significance in result indicated BIS protocol is not efficacious. It may be due to statistical power limitations. The results may also differ from expectation because of human error, system error or random error. It is difficult to predict what may be the underlying cause of failure. UK Health Technology Assessment (HTA) report also mentions the data of trial results, which is again inconclusive as there is no reproducibility of results. Thus, conclusion based on literatures on clinical trials is not the reliable way to assess the clinical effectiveness of BIS.

Inference from interviews: what stakeholders think about BIS:

The cost of BIS sensor strip seems to be beyond of their budget. The BIS monitor, though being clinically effective measure, does not seem much attractive from hospital administrator perspective. A few number of anaesthesiologists also found the new technology confusing due to difference between their clinical judgement about anaesthetic dose and objective solution by BIS resulted form of statistical algorithm. However, associating quality of life value to the cost analysis, BIS technology proved to be beneficial with strengths like ability to reduce awareness and its after-effects from most of health-economists. But, it was not found to be realistic support to recommend BIS technology while considering broader scenario.

Issues identified with BIS:

1. Purpose of use: Dose Titration or Depth of Anaesthesia??

The information available on BIS Education video¹¹ provides a sort of review on BIS technology. Most of anaesthesiologists use BIS index for dose titration but at the same time, the concept of using BIS as consciousness index is forgotten. BIS is useful in critical care patients as anaesthetists have to focus on critical condition's management of the patient but not the amount of dose of anaesthetic or depth of anaesthesia as it is governed by BIS.

2. Bi-spectral Index: Is it a trustworthy index?

It is the index derived with help of statistical signal processing. Most of studies support the fact that this calculation is only based on the fixed-effect model¹². Effect of random variables is not addressed in this model. Also human nervous system behaviour is complex. The BIS monitor is too naive to be able to individualize level of consciousness in form of a number. Moreover, it is also fact that BIS is not able to distinguish between deep and very deep level of sedations¹³. Inter-patient variability leads sometimes misinterpretation of BIS and thereby undesired way of management of the patient. BIS monitor is designed so as to compare current data with pre-fed statistical data. Hence, the patterns which are not configured in the data library will not be analysed properly using BIS algorithm¹⁴. To be more specific, BIS algorithm has not ability to adapt as

per variations in EEG signals variations. These variations may be from individual to individual or due to patients with data outside the expected norms applicable to healthy subjects with standard anaesthetic regimen. This in turn will reflect in improper correlation between level of sedation and BIS. Moreover, BIS is not able to predict haemodynamics of the patient unlikely the anaesthesiologists themselves. BIS index is derived from algorithm designed using subjective method. For the most of patients, BIS seems to be an significant determinant of Level of Consciousness (LOC). However, patients with pre-existing brain injury, those receiving nonstandard anaesthetics or statistical outliers may lead to erroneous results¹⁴. Being an electrical signal based index, BIS is subject to fluctuations depending on the artefacts resulted from EMG and other Electro-magnetic Interference (EMI) signals¹⁵. There is evidence where BIS fails to detect level of sedation while used with hypnotics like ketamine¹⁶ and fails to detect cerebral ischaemia in several awake surgeries¹⁷.

3. Ethical considerations:

Not only BIS sometimes produce misleading results but also puts clinical professionals using it in ethical question. A publication shows Brown's execution¹⁸ of lethal injection story. The gist of the story is sole reliance on BIS led to inappropriate judgement and false surety about patient's unconsciousness and eventually rendered the state protocol to undergo through modification. Initially the protocol had no compulsion on presence of qualified clinical professional while BIS based execution. But, after accusation from Brown, the state had to change the protocol that mandated arrangement of BIS in proximity to clinical professional so as to vigilate if BIS produces wrong results. The same report stated the fact from the BIS company's medical director that BIS should not be used alone without observer and its sales officer described it as "regrettable system failure" as unknowingly introduction of this technology seemed to tend to paralyse the human vigilance system.

4. Low resource Settings issues:

In low resource settings, accessibility to anaesthesia is the first and foremost consideration regardless of use of sophisticated technology in delivering anaesthesia. Moreover, It is well known fact that major proportion of healthcare users belonging to low resource health settings are with low socio-economic profile. It is not appropriate to subject them for out-of-pocket expenditures, which are most commonly associated with BIS. Resources limitation in resource-poor health settings may be in form of financial capital¹⁹, human resources and health technologies. Deployment of such a hi-tech equipment without considering the skills of available personnel to use it is also waste of valuable resources. This huge expense is highly likely to reflect in compromise in rest of resource allocation to rest of the personnel and technologies. Such inequitable distribution¹⁹ of human and health technology resources unknowingly becomes cause of injustice to healthcare users who don't have access or who don't need BIS like expensive

technology in their care and poses ethical question on the same.

To overcome personnel skills issue regarding use of BIS, there are suggestions on presence of BIS trainer during anaesthesia after few weeks of procurement of BIS unit. But, there are chances that most of the times, trainers are technical professionals rather clinical one. They may not be appropriate person to judge the level of anaesthesia. There is also a threat that knowledge of the BIS trainer may supersede the clinical experience of the anaesthesiologist and may render the anaesthesia go in inappropriate direction.

For a while, even if we consider BIS trainer presence a good solution, it is not practical solution. Considering the fact from ASPECT medical system inc. about their 39,990 installations, there will be requirement of at least 39,990 BIS trainers. It is not likely that only one trainer will be required for all the operations performed in a particular center. Thus, the number of trainers required will again go higher. Low –resource settings already run out of the budget. It is obviously not sensible to hire BIS trainers in such situation with full of resource scarcity. Instead of trainer's presence in Operation Theatre(OT), training sessions for anaesthesiologists after technology impact assessment may be thought of if needed.

5. Cost analysis and issues:

Enormously high cost of BIS monitor is always a matter of question. There is no justifying literature available why it costs so much. According to NICE costing statement²⁰, the cost of BIS monitor is divided in 2 parts – Main cost of unit plus recurring cost of sensors to be applied to patients. According to costing statement, BIS unit cost is £ 4350 (vista) and £ 5250 (bilateral vista). Most commonly used BIS sensor cost per patient is 14.08 £. Taking a look at Indian perspective, Indian Gross Domestic Product(GDP) per capita(Purchase Power Parity-PPP) is very less (\approx 4000 USD) compared to UK (\approx 32,000 USD) as per World Bank Report²¹. From the information from World Health Organization(WHO) site, % of Gross Domestic Product spent in healthcare expenditure²² for Indian Population is only 3.9%, which is again very less compared to UK one(9.3 %). Moreover, there is no costing statement available on BIS or any other Depth of anaesthesia monitors used in India from Government Health care Sector to provide insight on whether to choose such technology. Thus, it is highly recommended to perform economic viability analysis on local basis before procuring BIS monitor and not to just blindly follow the trend of using sophisticated technologies.

CONCLUSION

BIS monitor has started gaining popularity as the "unique technology for monitoring depth of anaesthesia". It is proven from reports ^{23 24 25} that BIS is not cost-effective and also clinical acumen always holds first position while considering Depth of anaesthesia judge-

ment. Chances are highly likely that in race of delivering health care with sophisticated technologies, resource-limited setting may also get directed in deploying BIS. But, accessibility of anaesthesia must be always prime consideration. There are several practical issues like inability of BIS to address heterogeneity due to internal variability amongst different patients and its reflections in terms of anaesthesia delivery, unproven cost-effectiveness, mixed results from clinical trials, lack of in-depth knowledge to comprehend BIS algorithm's actual functioning and low-budget of resource-poor settings. Anaesthesiologists have been trained to monitor anaesthetic depth and to manage incidence of awareness without BIS since era of beginning of anaesthesia so far. Moreover, Guedel's classification has been classic guide and its importance should never be outweighed by introduction of BIS. Thus, there is no doubt about clinical judgement of anaesthesiologist based on vigilance of vitals, clinical autonomic signs and comprehension of haemodynamics is the best determinant of depth of anaesthesia. It is sensible and plausible not to use BIS in low resource settings due to mainly training issues and unproven cost-effectiveness in literatures. However, this article never aimed at criticising BIS in negative manner. Thus, it is only recommended by authors to the anaesthesiologist and concerned health-care professionals to assess clinical need and organizational capacity before purchasing expensive technology because decision making should always be done on basis of local conditions and not solely on basis of literatures. At last, to analyse BIS just make sure it is not the case that "*after use of expensive BIS, patient may be out of awareness but not out of memory about cost that he/she had to pay for avoiding it!!*"

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