INTRODUCTION

Minimum alveolar concentration (MAC) derived from the end-tidal anaesthetic concentration is commonly used for monitoring depth of anaesthesia during general anaesthesia using volatile anaesthetics.\(^1\) Volatile anaesthetic agent monitoring facility is widely available in the present-day anaesthesia monitors. In human subjects, there is an age-dependent change in sensitivity to volatile agents, which is represented by a change in both MAC and MAC-awake with age. Each increasing decade of life is associated with a 6%–6.7% decrease in MAC.\(^2,3\) Anaesthesiologists not only monitor MAC but also plan anaesthesia with target MAC. The age of the patient is, however, required to be entered manually in the patient monitor. If age is not entered, the monitor will display the MAC for a
40–year-old patient by default.[4] We aimed to assess the practice of patient admission (birth year entry) in the anaesthetic agent monitor. In the second part of the study, we assessed the impact of wrong age entry on the observed MAC monitored in relation to the age-specific MAC (MAC<sub>age</sub>).

**METHODS**

After approvals from the authority, the study was conducted in two tertiary care teaching hospitals. Sixty volatile anaesthetic based-general anaesthetics (GAs) were observed silently (without the knowledge of the anaesthesiologist, surgeon and technician who were conducting the case) and patients’ admission in the monitor in terms of ‘birth year’ entry were noted at the starting and till the induction phase was over for the case.

The assessment of impact for age non-entry on MAC was done by noting the observed reading on the anaesthetic agent monitor, and then by noting the MAC<sub>age</sub> after entering the birth year in the patient monitor. No intervention to change the anaesthetic management of the ongoing GA was done. GAs where nitrous oxide was contraindicated and GAs which did not extend >20 min in the maintenance phase of anaesthesia were excluded from the second part of the study. The Mindray WATO EX 65 anaesthesia machine and Beneview T8 monitor (Mindray Medical International Limited, China) with anaesthetic agent monitoring facility were used. Isoflurane as well as sevoflurane (both from Abbott Laboratories, USA) were used for anaesthesia using the Mindray V60 and Drager Tec7 vaporiser, respectively. The age, sex, body weight, American Society of Anesthesiologists physical status and surgical category as per National Institute of Health and Clinical Excellence were noted.[5]

The observed MAC reading and MAC<sub>age</sub> data were taken during maintenance phase of anaesthesia at least 20 min after induction. Fixed fresh gas flow (FGF) of both oxygen and nitrous oxide (N<sub>2</sub>O) and dial settings of agents for at least 5 min were ensured (if any changes were done towards the end of 20 min of maintenance phase) before taking data. Total FGF, fraction of inspired (Fi) and fraction of expired (Fe) N<sub>2</sub>O and other volatile agents were also noted at the time of recording MAC data. Quantitative data were expressed in absolute number and percentage scale. Data were further analysed for measuring central tendencies and dispersions. MAC<sub>age</sub> and 0.7 MAC<sub>age</sub> were compared with monitored MAC using paired t-test. INSTAT software (GraphPad Prism Software, La Jolla, CA, USA) was used for statistical measurements and P < 0.05 was considered statistically significant.

**RESULTS**

There were 34 anaesthesiologists and anaesthesia residents in the two institutes where the study was performed; 21 of them were involved in the cases. Sixty volatile anaesthetic-based GA cases (aged between 10 and 68 years with mean [95% confidence interval [CI]] 36.73 [32.67–40.78] years; 38 [63.33%] females and 22 [36.67%] males) were observed. On twenty-two occasions, it was required to change the patient type (i.e., adult, paediatric and infant) in patient monitor; this was done in 19 (86.36%) occasions. In all the sixty cases, the birth year was required to be changed/entered. However, 58 (96.67%) of the observed anaesthetics were conducted without entering or changing the ‘birth year’ in the monitor.

Twenty-six GAs were excluded as per exclusion criteria for comparison of MAC values. Data from 34 eligible GAs (22 [64.71%] female, 12 [35.29%] male) were collected for comparison of observed MAC and MAC<sub>age</sub>. The age groups, surgical categories and physical status of the cohort for MAC comparison are presented in Table 1. Nine (26.47%) patients had comorbid medical conditions such as obesity, hypertension, hypothyroidism, diabetes mellitus and chronic obstructive pulmonary diseases either singly or in different combinations.

Twenty-four (70.59%) GAs were conducted using isoflurane. The mean ± standard deviation (SD) (95% CI) FGF of sevoflurane was significantly higher than isoflurane (1730 ± 565.78 [1325.3–2134.7] ml vs. 654.08 ± 123.78 [599.81–704.36] ml; P < 0.0001). The mean ± SD of FiN<sub>2</sub>O, Fi isoflurane and Fi sevoflurane was 55.00 ± 4.69, 1.084 ± 0.16 and 1.546 ± 0.309, respectively, and FeN<sub>2</sub>O, Fe isoflurane and Fe sevoflurane 50.47 ± 4.91, 0.948 ± 0.14 and 1.23 ± 0.205, respectively, at the time of taking MAC readings.

The observed MAC was comparable with the MAC<sub>age</sub> in the age group of 36–45 years (P > 0.05). It was significantly higher in the patients aged <35 years and lower in patients aged >46 years. In 27 (79.41%) out of 34 patients, the observed MAC values were
significantly erroneous; 19 (55.88%) of the observed MAC values were higher than age-corrected MAC ($\text{MAC}_{\text{age}}$), whereas 8 (23.53%) were lower than $\text{MAC}_{\text{age}}$. If the cases would have been conducted with target MAC (without entering birth year in patient monitor), 55.88% patients of the patients aged $<35$ years would have been potentially prone for underdosing whereas 23.53% patients aged $>46$ years would have been exposed to excess anaesthetic agent. However, in the current cohort, all patients (including patients up to 10 years of age) were found to have the observed MAC above the threshold of MAC awareness (0.7 $\text{MAC}_{\text{age}}$) [Table 2].

**DISCUSSION**

Volatile anaesthetics have been playing a central role in anaesthetic practice for nearly 170 years.[1] The concept of MAC was introduced in 1965 as a measure of anaesthetic potency and has remained a standard for the purpose.[6] Anaesthetic gas monitoring has evolved into a de facto standard of care in anaesthetic practice.[7] Respiratory gas analysis has become an integral part of the present-day anaesthesia workstations. With the increasing use of low flow anaesthesia, the need of gas analysers is even more essential.[8] The Associations of Anaesthetists of Great Britain and Ireland states that the use of a vapour analyser is essential during anaesthesia whenever a volatile anaesthetic agent or nitrous oxide is in use.[9] It also recommends that accurate records of the values determined by monitors must be kept and even included vapour concentration (end-tidal concentration) monitoring along with heart rate, blood pressure, etc., in the minimum data to be recorded.[9] As MAC is calculated from the end-tidal concentrations of anaesthetic agents, MAC monitoring can also be regarded as one of the minimum monitoring standards.

MAC was defined as alveolar concentration at which 50% of patients will not show a motor response to a standardised surgical incision at one atmosphere.[1] It is also a surrogate of depth of anaesthesia. Anaesthetic agent monitors derive the MAC from the end-tidal concentration (alveolar concentration) of the anaesthetic agent. The alveolar concentrations for different agents for deriving MAC values are published by the United States Food and Drug Administration for a healthy 40-year-old male patient.[4] For the patients of other ages, the monitor uses an algorithm to derive the MAC corrected for the age of the patient ($\text{MAC}_{\text{age}}$), which needs patients age[4] to be entered in the monitor

$$\text{MAC}_{\text{age}} = \text{MAC}_{40} \times 10^{-0.00269 \times \text{[age-40]}}$$

where $\text{MAC}_{40}$ -MAC standard or default for a healthy 40-year-old male patient.[4]

Therefore, to get accurate, reliable and appropriate MAC ($\text{MAC}_{\text{age}}$), entry of the patients’ age in the monitor

**Table 1: Age, weight, physical class and surgical grade of the cohort analysed for age minimum alveolar concentration interaction**

| Parameters                      | Mean±SD/n (%)/median (IQR) |
|---------------------------------|----------------------------|
| Age (years)                     | 35.14±15.38                |
| (Mean±SD)                      |                            |
| ≤25 years                       | 10 (29.41)                 |
| n (%)                          |                            |
| 26-35 years                     | 9 (26.47)                  |
| n (%)                          |                            |
| 3645 years                      | 6 (17.65)                  |
| n (%)                          |                            |
| 46-55 years                     | 5 (14.71)                  |
| n (%)                          |                            |
| ≥56 years                       | 4 (11.76)                  |
| n (%)                          |                            |
| Weight (kg)                     | 56.67±18.30                |
| ASA (Median, [IQR])            |                            |
| I (n [%])                      | 12 (35.294)                |
| II (n [%])                     | 18 (52.941)                |
| III (n [%])                    | 4 (11.765)                 |
| Surgical grade (Median, [IQR]) |                            |
| 1 (n [%])                      | 3 (8.824)                  |
| 2 (n [%])                      | 8 (23.53)                  |
| 3 (n [%])                      | 21 (61.764)                |
| 4 (n [%])                      | 2 (5.882)                  |

ASA – American Society of anesthesiologists; SD – Standard deviation; CI – Confidence interval; IQR – Interquartile range

**Table 2: Comparison of mean±standard deviation of monitored minimum alveolar concentration, $\text{MAC}_{\text{age}}$ and their ratio analysed using paired t-test**

| Age group (year) | Monitored MAC (reference) | Actual MAC $\text{MAC}_{\text{age}}$ | $\text{MAC}_{\text{age}}$: MAC monitored | $P$    |
|------------------|---------------------------|--------------------------------------|------------------------------------------|--------|
| 10-15            | 1.17±0.128                | 0.98±0.115                           | 0.837                                    | <0.0001|
| 16-25            | 1.08±0.069                | 0.981±0.092                          | 0.908                                    | 0.0005 |
| 26-35            | 1.223±0.119               | 1.157±0.121                          | 0.946                                    | <0.0001|
| 36-45            | 1.208±0.091               | 1.201±0.092                          | 0.994                                    | 0.174  |
| 46-55            | 1.092±0.125               | 1.188±0.094                          | 1.087                                    | 0.020  |
| 56-68            | 1.117±0.158               | 1.285±0.143                          | 1.150                                    | 0.001  |

MAC – Minimum alveolar concentration; $\text{MAC}_{\text{age}}$ – MAC corrected for age
Karim, et al.: Birth year entry and MAC monitoring

is must. Otherwise, the monitor by default displays
the MAC value for a 40 year old patient. Changing the
patient type from adult, paediatric or infant, changes
the default settings of haemodynamics and ventilation
but not the MAC default. Further, if previously a
65 year old patient was admitted and the next patient,
a 15 year old, is taken without restarting or readmitting
the patient in the monitor, the monitor will display the
MAC value for a 65 year old patient, and not the default
for a 40 year old patient. Recent evidence suggests
that the protocol which alerts anaesthesiologists
whenever end-tidal anaesthetic concentration falls to
0.7 MAC has the potential to decrease intra-operative
awareness with explicit recall.\textsuperscript{[10]} This indicates
that a 30% variation (low record) of MAC may lead
to awareness. If we take the previous example, the
latter patient is potentially in the range of awareness
(6.7%/decade × 5 decades = 33.5% variation).
Although in the present cohort, the mean MAC\textsubscript{age} and
observed MAC ratio as well as values were not <0.7;
from the above example, it is clear that age non-entry
can leave a young patient potentially in awareness
range.

Wrong age entry in the patient record at the time of
hospital admission also does happen, especially in
illiterate patients. The present study finding indicates
that if the age entered in the monitor is within 5 years
of the patient’s correct age, the monitored MAC will
be statistically indifferent from MAC\textsubscript{age} 95% of times.

There are few data on awareness during anesthesia
from the Indian population. One study has concluded
that the incidence is <1 in 300 (0.33%).\textsuperscript{[11]} However,
awareness under anaesthesia is distressing and has a
potential for long-term consequences. It is also opined
that every effort should be undertaken to prevent it.\textsuperscript{[11]} Anaesthesia hazards can happen both due to the
equipment failure and human error. Hardware failures
in modern anaesthesia delivery equipment leading to
hazards are uncommon.\textsuperscript{[12]} It is rather more common
due to the unintentional misuse of the equipment,
human error or equipment failure without the user
being aware that a failure had taken place.\textsuperscript{[12]} The
present study finding of 96% of ‘birth year’ non-entry
in the monitor leading to incorrect readings can be
regarded as a human error which can potentially
culminate in hazards of overdose, underdosing and
even awareness. This error can be avoided by making
‘birth year’ entry as a part of checklist before starting
any case. The monitor software also probably can be
configured in future to prompt ‘birth year’ entry
in the monitor or machine before displaying agent
monitoring values or starting the cases and even when
monitor is activated to measure mode from standby
mode.

Misinterpretation of MAC value in context to age has
been reported before too.\textsuperscript{[13]} However, the present study
finding of patient age not being entered in 96% of all
anaesthetics, leading to erroneous MAC readings in 79%
of these indicates that this issue needs to be publicised
more. Avoiding this simple and common human error
can have a major impact on MAC monitoring.

The present study is limited with regard to observations
made in only two hospitals with small samples.
Moreover, the case mixes, especially age group
variation are also very much likely to be different in
different hospitals. However, the very high percentage
of wrong MAC recording indicates that the finding is
likely to have a strong implication in clinical practice.

CONCLUSION

Patient’s age entry in the monitor was rarely practiced.
This human error, in turn, resulted in wrong MAC
values being displayed and potentially exposed
patients younger than 40 years to underdosing and
older patients to drug overdose. We suggest that entry
of patients’ age in the anaesthetic agent monitor should
be included as one of the items in the preoperative
checklist before starting a case.

Financial support and sponsorship
Nil.

Conflicts of interest
There are no conflicts of interest.

REFERENCES

1. Eger EI 2\textsuperscript{nd}, Saidman LJ, Brandstater B. Minimum alveolar
anesthetic concentration: A standard of anesthetic potency.
Anesthesiology 1965;26:756-63.
2. Mapleson WW. Effect of age on MAC in humans: A
meta-analysis. Br J Anaesth 1996;76:179-85.
3. Eger EI 2\textsuperscript{nd}. Age, minimum alveolar anesthetic concentration,
and minimum alveolar anesthetic concentration-awake.
Anesth Analg 2001;93:947-53.
4. Mindray MAC values. In: Beneview T8 Patient Monitor:
Operator’s Manual. Shenzhen: Shenzhen Mindray Bio-Medical
Electronics Co. Ltd.; 2016. p. 22-3.
5. National Guideline Centre (UK). Preoperative Tests (Update):
Routine Preoperative Tests for Elective Surgery. NICE
Guideline No. 45. London: National Institute for Health and
Care Excellence (UK); 2016. Available from: https://www.nice.
org.uk/guidance/ng45/chapter/recommendations. [Last cited
on 2016 Dec 24].
6. Bovill JG. Inhalation anaesthesia: From diethyl ether to xenon. Handb Exp Pharmacol 2008;182:121-42.
7. Langton JA, Hutton A. Respiratory gas analysis. Contiu Educa Anaesth Crit Care Pain 2009;9:19-23.
8. Garg R, Gupta RC. Analysis of oxygen, anaesthesia agent and flows in anaesthesia machine. Indian J Anaesth 2013;57:481-8.
9. Checketts MR, Alladi R, Ferguson K, Gemmell L, Handy JM, Klein AA, et al. Recommendations for standards of monitoring during anaesthesia and recovery 2015: Association of Anaesthetists of Great Britain and Ireland. Anaesthesia 2016;71:85-93.
10. Aranake A, Mashour GA, Avidan MS. Minimum alveolar concentration: Ongoing relevance and clinical utility. Anaesthesia 2013;68:512-22.
11. Ambulkar RP, Agarwal V, Ranganathan P, Divatia JV. Awareness during general anesthesia: An Indian viewpoint. J Anaesthesiol Clin Pharmacol 2016;32:453-7.
12. Eisenkraft JB. Hazards of the anesthesia workstation. ASA Refresh Courses in Anesthesiology. Vol. 37. Philadelphia: Lippincot Williams & Wilkins; 2009. p. 37-55.
13. Byrappa V, Kamath S, Venkataramaiah S. Misinterpretation of minimum alveolar concentration: Importance of entering demographic variables. Indian J Anaesth 2014;58:504-5.