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Original Article

A Prospective Interventional Study on the Application of Lean Six Sigma DMAIC Methodology on Assessing and Improving Antimicrobial Stewardship in a Tertiary Trauma Care Hospital, Coimbatore, India

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ABSTRACT

Background: Antimicrobial stewardship is referred as a concerted endeavor to ensure proper usage of antibiotics and deviations in programme leads to inappropriate use of antimicrobials, hence it requires standard tool to evaluate usage and measure improvement by alleviating deviations. The objective of the study is to observe antimicrobial stewardship activities in surgical patients and to develop comparison between antimicrobial recommending techniques with standard guideline available within hospital. To identify suitable variables or factors to measure antimicrobial stewardship and thereby accomplish recommendations for rational use of antimicrobials. **Materials and Methods:** The study was conducted in the department of orthopedics and plastic surgery, in a major trauma care centre in Tamil Nadu, India over a period of two years. The study was performed by using lean six sigma DMAIC tool. **Results:** In the current study, implementation of Lean Six Sigma DMAIC methodology revealed significant decrease in guideline errors, irregular follow ups, improper antibiotic usage and prescribing errors. Correspondingly, Six Sigma level improved from 1.1, 2.47, 3.87, 3.35 to 1.57, 2.55, 4.02 and 3.61 respectively. **Conclusion:** The study concluded that, by reducing antibiotic associated errors, such as inappropriate usage of antibiotics, prophylaxis use of higher end antibiotics, unrestricted duration of use and economic burden related to antibiotic treatment can be reduced. This can have a direct impact on improving patient safety and better clinical outcome.

Keywords: Antimicrobial, Stewardship, DMAIC, Six Sigma, Safety, Rational Use.

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INTRODUCTION

The treatment of antibacterial agents is one of the cornerstones of modern medicine, having recently become feasible during the past 60 years.[1] Antibiotics are like a weapon to the society which is exclusively abused by all the population due to their easy availability, generally low cost and relative safety. Engaging with bacteria that are resistant to antibiotics requires better antibiotic prescribing practices in healthcare settings.[2]

A basic understanding of the fundamental concepts of microbiology and the unintended consequences of antibiotic use is necessary for the effective and optimal prescription and management of antibiotics.[3] Uncertainty about the existence of spread of infection, postponed test results, physician limitations on time, the possibility of inadequate follow up with patients, understanding of present therapy recommendations, free or inflated antibiotic initiatives and concern about lawsuits if a curable infection goes unnoticed are just a few of the many factors that contribute to inappropriate antibiotic prescribing practices.[4]

Antibiotic use and the emergence of antibiotic resistance are inextricably linked. The improper use of antibiotics and the global spread of resistance are current issues that demands an immediate gesture to attain a universal cure. With a report detailing resistance to widely used antibiotics worldwide, the World Health Organization has highlighted the increasing trend of antimicrobial resistance and the impending public health crisis it will cause. According to estimates, drug-resistant bacteria cause almost 23,000 fatalities and over 2 million infections in the US each year.[5] India and the rest of the world are in an emergency due to rising drug resistance pathogens and an inadequate new antibiotic. Indian hospitals are reporting high levels of resistance to polymyxins, carbapenems and fluoroquinolones.[6] Due to varying antimicrobial usage policies and public hygiene standards

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amongst countries, Asia exhibits notable geographic variations in the resistance of various bacterial and fungal pathogens when compared to Western countries.[7]

In our day-to-day life we have come across a majority of antibiotics and we are also involved in creating a initiation of resistance patterns. A study conducted by the American Academy of Paediatrics stated that 40% of pediatricians reported that parents always or frequently insist on prescribing antibiotics when their children are sick, even though the drugs are not indicated. Of the pediatricians, 48% or more reported that a parent had requested an antibiotic 10 times or more when the physician did not feel it was suggested.[8]

Antimicrobial Stewardship (AMS) Program encourages the responsible use of antimicrobials, including antibiotics, enhances patient outcomes, lowers microbial resistance and slows the spread of infections brought on by organisms that are resistant to multiple drugs. It is the endeavour to assess and enhance the prescribing of antibiotics pattern followed by the physicians and to ensure that the rational use and prescription of antibiotics. Antimicrobial stewardship minimizes A postponed diagnosis resulting in antibiotic insufficient use and the assurance that, when an antibiotic is necessary, the appropriate medication, dosage and length of time are chosen.[9] The first and foremost concern of the AMS program relies on the ideology of no fight today can lead to no cure tomorrow.

The process and monitoring flow in the AMS activities conducted in a hospital has been shown in Figure 1. The antibiotic use has been appropriately classified into three sub classes namely, prophylaxis (use before the surgical procedures), empirical (suspecting an infection and initiating antibiotics based on local antibiogram after sending culture samples) and definitive (use of antibiotics based on the culture reports). An effective AMS improvement program starts with a thorough analysis of the factors determining the necessary use of antibiotics. Efforts that are specific to the challenges, the target group and the environment in which the change is to occur can lead to improved medical practices.[10]

The Indian Council of Medical Research (ICMR) has established standard guidelines for the efficient use of antibiotics as listed below:

- Establishing a medical diagnosis,
- Reducing the use of empirical antibiotics,
- Know the bugs,
- Select the effective antibiotic,
- Modification regarding de-escalation or escalation,
- Stop the antibiotics in certain medical conditions like RTI, pyuria, asymptomatic bacteriuria, etc.,
- Decrease the therapy duration.

Optimize PK-PD parameters

This study mainly focuses on diminishing the defects in the antibiotic usage practices by recommending new standards for appropriate antibiotic use by the application of Six Sigma DMAIC methodology. The elimination of errors in the antibiotic usage abruptly helps in the reduction of inappropriate use which represents as our main aim and objective.[11]

MATERIALS AND METHODS

Prospective interventional study by applying lean six sigma DMAIC methodology. Patients receiving antimicrobial therapy irrespective of age, gender, type of infection and type of surgery were included in the study. Use of antimicrobials at outpatient's setup and use of antimicrobials on other than surgical in-patients were excluded from the study.

Study Tool: Six Sigma DMAIC Methodology

Six sigma is a systematic, data-centered, mathematically relying approach and perpetual enhancement technique for getting rid of or cutting down on process flaws. It bridges the relationship between the quantity of standard deviations discovered in a given method and the quantity of defects per million opportunities. In technical terms, six sigma refers to any procedure, merchandise, or services having no more than 3.4 defects per million opportunities. The goal is to redesign a given process to Six Sigma specification ensuring that the process is 99.99975% error free.[12] Six sigma can also operate on the concept of DMAIC. It includes 5 phases: Define, Measure, Analyse, Improve and Control.

$$\text{DPU (Defects per unit)} = \frac{\text{Number of defects}}{\text{Number of samples}}$$

$$\text{DPMO (Defects per million opportunities)} = \frac{Number\ of\ defects}{Number\ of\ sample \times \text{Number of DPU}} \text{X } 100$$

Study Type: Prospective observational and interventional study.

Purpose: Judicial and rational use of antibiotics.

Source of Data: Patient case sheet, laboratory report, hospital antibiogram, treatment chart, supported tools/documents for study such as DMAIC, questionnaires, audit sheets, pharmacy software, HIS.

Study Location: Department of Orthopedics and Plastic Surgery, Ganga Medical Centre and Hospital Pvt Ltd., Coimbatore, Tamil Nadu, India.

Duration of Study: The study was conducted for a period of two years.

Sample size: Convenient sampling.

Plan of the study: Illustrated below in Figure 2.

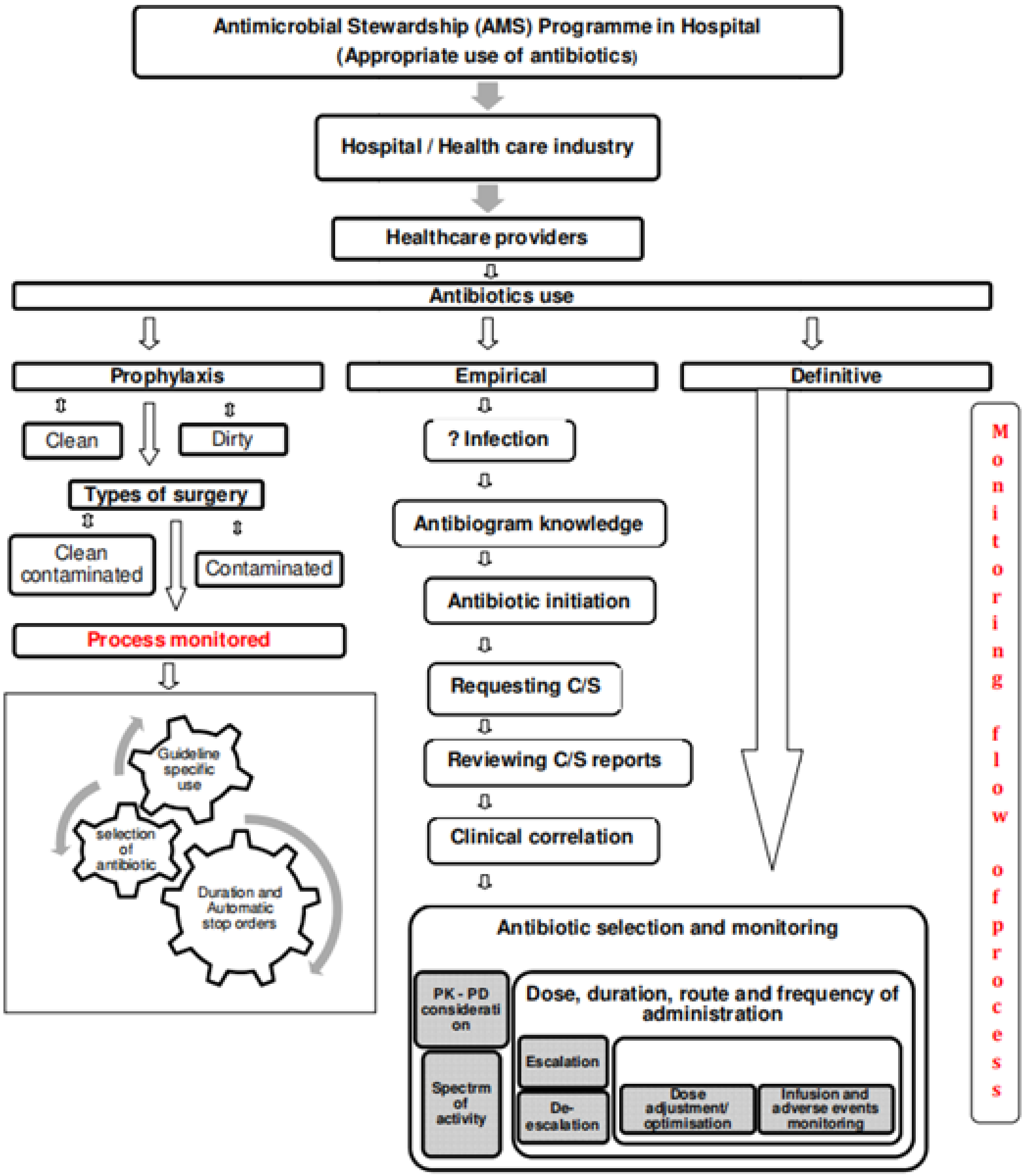

Figure 1: Monitoring process of Antimicrobial Stewardship Activities.

Ethics statement: Obtained from Institutional review board, Ganga Medical Centre and Hospitals Pvt Ltd., Coimbatore-641043, Tamil Nadu, India. (Registered with CDSCO, Regn No: ECR/1146/Inst/TN/2018, NECR BHR Regn No: EC/NEW/INST/2020/1146; IRB Application NO: 2022/01/03 Dated 03.01.2022).

Study procedure

In this study, total of 100, 1025, 1025, 100 patients were reviewed respectively in Phase I, Phase II, Phase IV and Phase V. The patient baseline clinical pictures such as age, gender, co-morbidities, diagnosis were compared. Further the patient data were assessed with and without culture report, antimicrobial usage along with wound details. An improvement in the usage pattern and reduction in unjustified culture reports was observed. The errors found from the Phase II (Measure Phase) of the study were standard guideline error; follow up error, wrong usage error and prescribing errors. The root cause of the errors observed were determined using fish bone analysis in the phase III (Analyse phase). The analyze phase has a major impact on the study as it is involved in observing the Failure mode and effect analysis (FMEA) and the calculation of Risk Priority Number (RPN) using the formula

Risk Priority Number (RPN)=Severity X Occurrence X Detection

The scale for determining the severity, occurrence and detection is mentioned below in Tables 1-3 respectively.

Action plan was made and implemented in the phase IV (Improve Phase) to reduce the total number of errors. An increase in the sigma value was observed in the phase IV when compared to phase II. Standard antimicrobial stewardship practices were observed in phase V (Control Phase).

RESULTS

A total of 2,250 patient data were observed for the AMS activity over the period of two years. In this study, a quality improvement tool named Six Sigma DMAIC methodology was applied in five phases namely: Define, Measure, Analyse, Improve and Control phase to eliminate the defects in the antibiotic prescribing pattern and thereby avoid the inappropriate use of antimicrobials.

Define Phase

The initial process of the define phase commences with the Value Stream Mapping (VSM) (Figure 3) for AMS Practices conducted in the hospital which identifies and segregates the entire process based on their importance as value added and non-value-added steps. The main aim is to strengthen the value-added process by assessing the AMS practices and to minimize or eliminate the non-value-added process thereby improving the AMS practices in the hospital setup.

Further, in this phase, data collection form was formulated and phase I study was conducted with 100 patient data to evaluate the major defect producing factor. There were total of 34 errors that were grouped as follows; 15 (44.12%) standard guideline errors, 6 (17.65%) follow up errors, 3 (8.82%) improper usage errors and 10 (29.41%) prescribing errors (Table 4) and described in the Pareto chart (Figure 4). SIPOC chart (Table 5) and project charter (Table 6) were developed to define the problem statement of the study.

Table 1: Scale for severity.

Rating	Description	Impact
1	Negligible	No harm
2	Marginable	Minor harm
3	Moderate	Moderate harm
4	Major	Significant harm
5	Critical	Serious harm or death

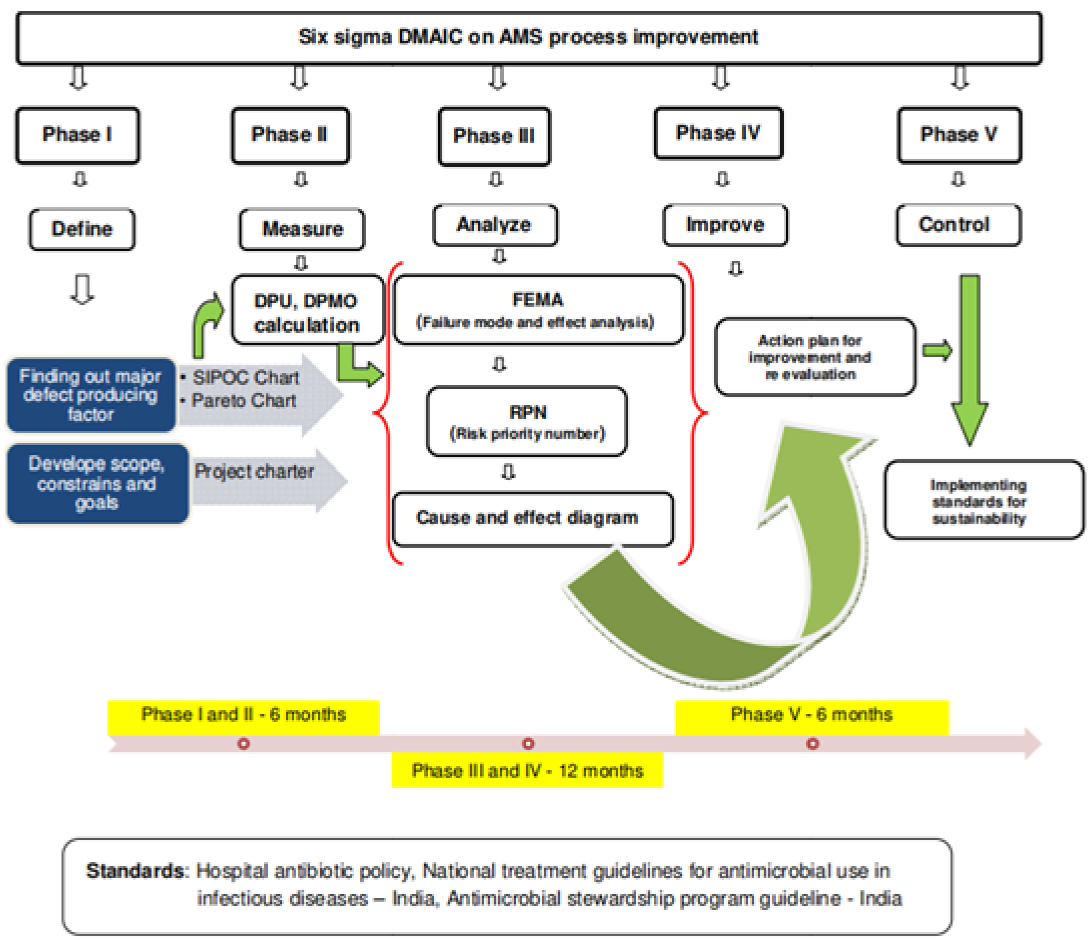

Figure 2: Study plan-Six sigma DMAIC phases on AMS process improvement.

Table 2: Scale for occurrence.

Rating	Description	Impact
1	Extremely unlikely	<1 in 1025
2	Far-flung	<1 in 500
3	Occasional	<1 in 250
4	Probable	<1 in 100
5	Frequent	Again, and again

Table 3: Scale for detection

Rating	Description	Impact
1	Very high	Detection is highly effective
2	High	Detection is somewhat effective
3	Moderate	Detection is suspect
4	Low	Detection is weak
5	Very low	Detection is ineffective

Table 4: Phase I study - Type of error.

Type of error	No. of error	Cumulative	Percentage	Cumulative %
Standard guideline error	15	15	44.12%	44.12%
Prescribing error	10	25	29.41%	73.53%
Follow-up error	6	31	17.65%	91.18%
Improper usage error	3	34	8.82%	100.00%

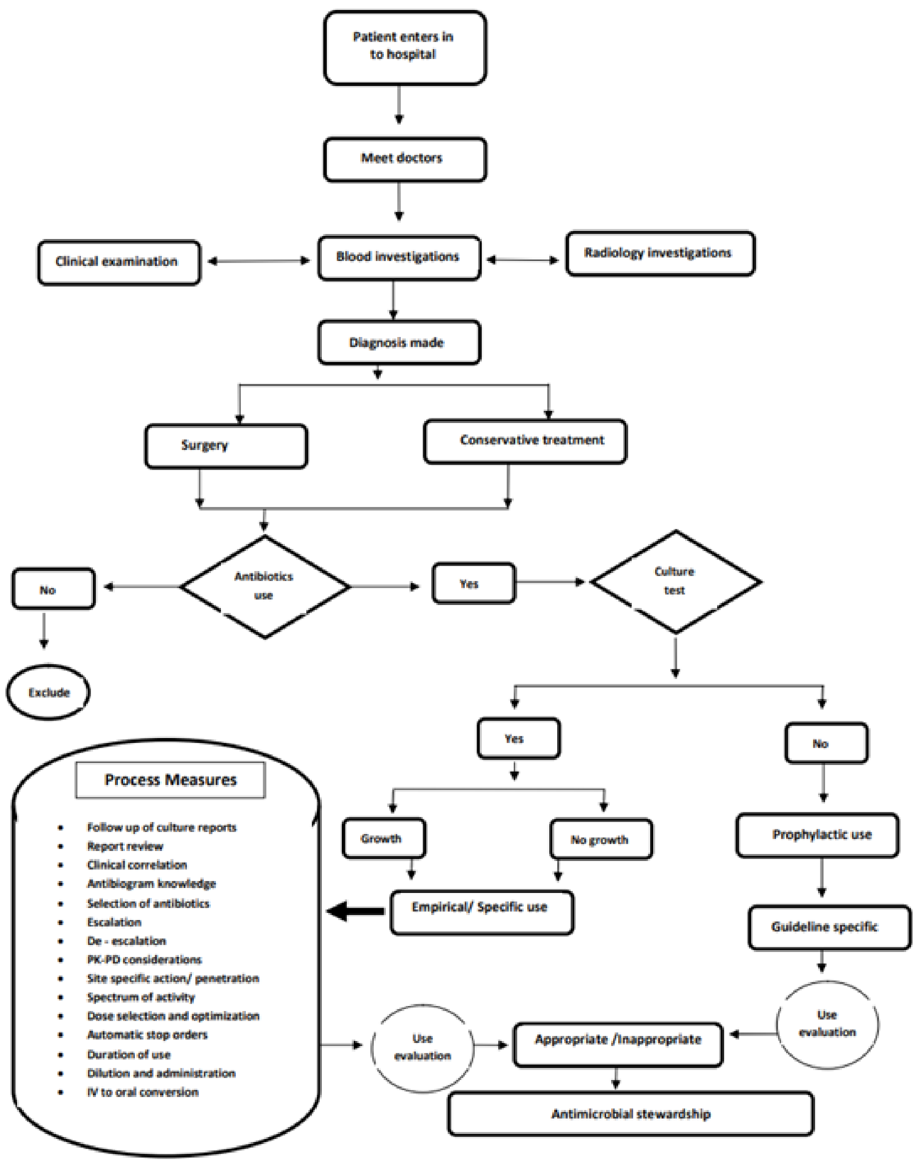

Figure 3: Value Stream Mapping-Antimicrobial Stewardship Practices.

Measure Phase

The measure phase categorized the different defects of the study into major streams namely, standard guidelines errors, follow up errors, improper usage errors and prescribing errors. The total numbers of errors in each category were quantified and defects per unit, defects per million opportunities, Sigma calculations were established. Out of 1025 patient data reviewed in the measure phase, there were 672 errors due to the deviations from Standard Guidelines, 171 errors in Follow Up, 9 errors in Improper Usage of Antibiotics and 33 errors in Prescribing antibiotics followed by sigma levels of 1.1, 2.5, 3.9 and 3.4 respectively.

Table 5: SIPOC chart.

SIPOC Chart for AMS Process	
Supplier	Health care provider in healthcare industry
Input	Antibiotic practices.
Process steps	Rational use of antibiotics.
Output	Good antimicrobial stewardship practice.
Customer	Patients

Analyze Phase

In this phase the patient data are analyzed and the Risk Priority Number (RPN) is calculated from Failure Mode and Effect

Table 6: Project charter.

Project Charter for AMS Process Improvement	
Project title	Application of lean six sigma DMAIC methodology on assessing and improving antimicrobial stewardship in a major trauma care hospital.
Clinical need	Antibiotic resistance is one of the major threats to human health; especially some bacteria have developed resistance to all known classes of antibiotics. Diseases caused by these bacteria are increasing in long term care facilities and contributing to higher rates of morbidity and mortality. This study is conducted to improve rational use of antibiotics and thereby help in controlling the resistance of bugs.
Problem statement	Antibiotics usage error can be caused by number of factors such as lack of knowledge, inexperienced personnel, poor clinical correlation, poor communication, etc. Any one of these or a combination can affect the prescribing, follow-up, usage and monitoring of antibiotics and its uses, which can directly result in inappropriate use of it.
Goal statement	The goal is to improvise antibiotic stewardship activities and reduce the errors from the baseline to reach a process Sigma of Six in defects per million opportunities.
Project scope	The scope of this project is to identify the root causes leading to different errors associated with antibiotics usage practices and to implement strategies to improve antibiotic stewardship activities.

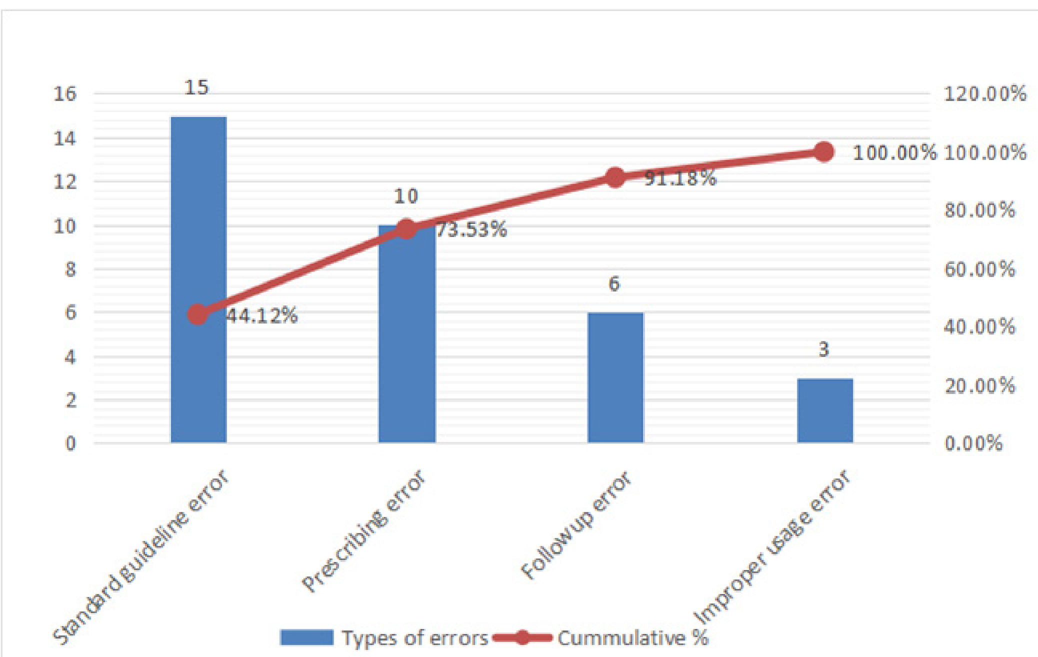

Figure 4: Pareto chart-Define phase.

Analysis (FMEA) for the data obtained in the measure phase which is depicted in Table 7.

Improve Phase

In this phase, the action plan listed in Table 8 was executed and the enhancement was established by following some of the guidelines provided below in the fish bone diagram (Figures 5 and 6). The comparison and the improvement in the RPN - FMEA analysis between Phase II and Phase IV are depicted in Table 9.

After the implementation of the action plan, the improvement was attained. Out of 1025 data in the improvement phase, 485 errors due to deviations in Standard Guidelines, 151 errors in Follow Up, 6 errors in Improper Usage of Antibiotics and 18 errors in Prescribing antibiotics were observed followed by sigma

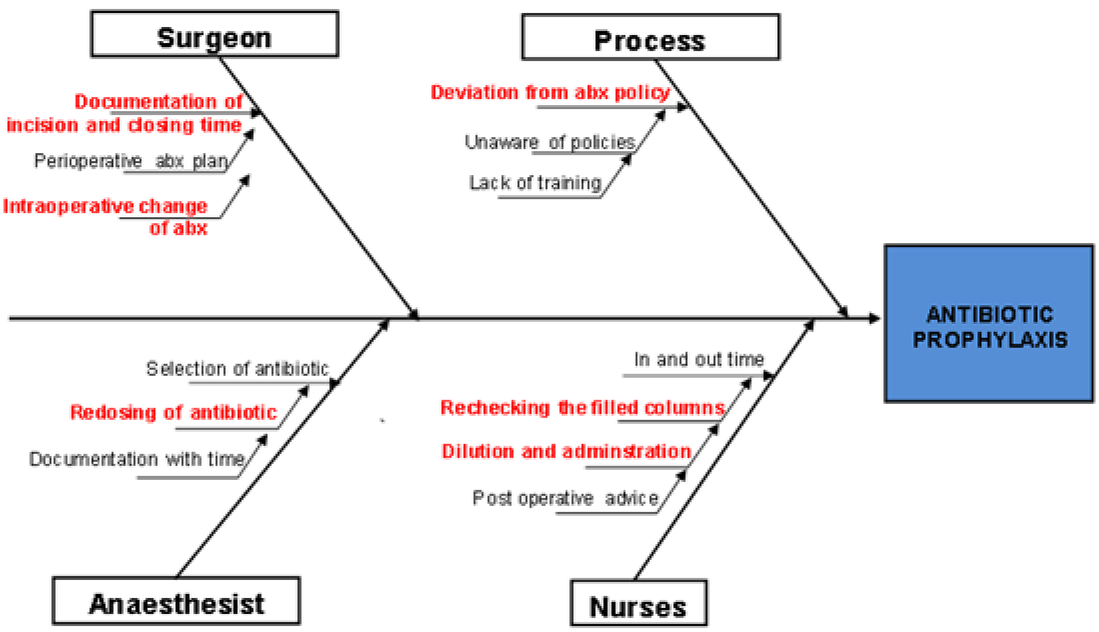

Figure 5: Fishbone Diagram-Antibiotic Prophylaxis.

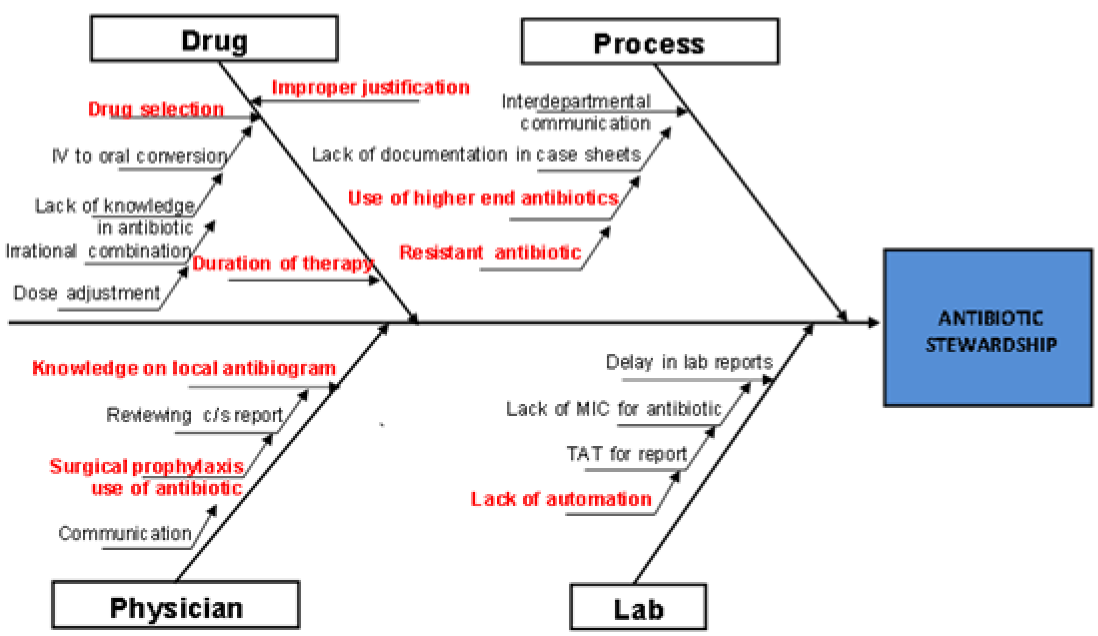

Figure 6: Fishbone Diagram-Antibiotic stewardship.

Table 7: Failure mode and effect analysis-Measure Phase.

Process Step	Potential Failure Mode	Potential Failure Effect	Severity	Potential Causes	Occurrence	Current Process Controls	Detection	RPN	Action Recommended
Standard Guidelines Errors	i) Empirical therapy without culture report.	i) Delay in initiating standard treatment.	2	Inadequate knowledge on standard guidelines of antibiotic use and clinical correlation.	5	Providing education regarding the standard guidelines of antibiotic usage to the healthcare professionals.	2	20	To conduct frequent audits on antibiotic usage and to create awareness on appropriate use of antibiotics.
	ii) Improper antimicrobial coverage.	ii) Delay in therapeutic outcome.	3		4		1	12	
	iii) Deviation from standard antibiotic prophylaxis	iii) Increase in risk of infection.	3		4		1	12	
	iv) Poor clinical correlation.	iv) Prolonged hospitalisation.	4		3		1	12	
Follow up errors	i) Continuing Resistant drug.	i) Delay in therapeutic outcome.	3	Improper communication between healthcare workers due to heavy workload.	3	Establish electronic updates on lab reports and reminders.	2	18	To enable system generated laboratory reports specially for C/S.
	ii) Lack of reviewing C/S reports.	ii) Delay in targeting pathogen/ treatment.	2		4		2	16	
	iii) IV to oral switch over	iii) Increase in health care cost	1		3		3	9	
Improper Usage Errors	i) Poor drug optimization.	i) Individualized drug therapy not attained.	3	Insufficient clinical correlation and inadequate understanding of drug use.	3	Basic training programs on clinical interpretation and drug utilization.	1	9	To conduct regular training sessions and regular audit on it.
	ii) Deviation from standard frequency setting.	ii) Variation in therapy effectiveness.	3		3		2	18	
	iii) Deviation from standard duration.	iii) Discrepancy in healthcare cost.	3		3		2	18	
	iv) Poor justification.	iv) Increase in resistant rate.	3		3		2	18	
Prescribing errors	i) Lack of review of antibiotic prescriptions.	i) Inappropriate use of antibiotics.	3	Lack of knowledge on standard guidelines.	3	Conducting regular audits on usage of antibiotics.	1	9	To implement often due and point prevalent studies.

Table 8: Failure mode and effect analysis-Improve Phase.

Process step	Potential failure mode	Potential failure effect	Severity	Potential causes	Occurrence	Current process controls	Detection	RPN	Action recommended
Standard Guidelines Errors	i) Empirical therapy without culture report.	i) Delay in initiating standard treatment.	2	Inadequate knowledge on standard guidelines of antibiotic use and clinical correlation.	5	Providing education regarding the standard guidelines of antibiotic usage to the healthcare professionals.	2	20	To conduct frequent audits on antibiotic usage and to create awareness on appropriate use of antibiotics.
	ii) Improper antimicrobial coverage.	ii) Delay in therapeutic outcome.	3		4		1	12	
	iii) Deviation from standard antibiotic prophylaxis.	iii) Increase in risk of infection.	3		3		1	9	
	iv) Poor clinical correlation	iv) Prolonged hospitalisation	4		2		1	8	
Follow up errors	i) Continuing Resistant drug.	i) Delay in therapeutic outcome	3	Improper communication between healthcare workers due to heavy workload.	2	Establish electronic updates on lab reports and reminders.	2	12	To enable system generated laboratory reports specially for C/S.
	ii) Lack of reviewing C/S reports.	ii) Delay in targeting pathogen/treatment.	2		4		2	16	
	iii) IV to oral switch over.	Increase in healthcare cost.	1		2		3	6	
Improper Usage Errors	i) Poor drug optimization.	i) Individualised drug therapy not attained.	3	Insufficient clinical correlation and inadequate understanding of drug use.	2	Basic training programs on clinical interpretation and drug utilization.	1	6	To conduct regular training sessions and regular audit on it.
	ii) Deviation from standard frequency setting.	ii) Variation in therapy effectiveness.	3		2		2	12	
	iii) Deviation from standard duration.	iii) Discrepancy in healthcare cost.	3		3		2	18	
	iv) Poor justification.	iv) Increase in resistant rate.	3		2		2	12	
Prescribing errors	i) Lack of review of antibiotic prescriptions.	Inappropriate use of antibiotics.	3	Lack of knowledge on standard guidelines.	1	Conducting regular audits on usage of antibiotics.	1	3	To implement often DUE and prevalent studies.

Table 9: RPN comparison- Failure mode and effect analysis.

Process step	Potential Failure Mode	Phase II				Phase IV			
		SEV	OCC	DET	RPN	SEV	OCC	DET	RPN
Standard guidelines errors	i) Empirical therapy without culture report.	2	5	2	20	2	5	2	20
	ii) Improper antimicrobial coverage.	3	4	1	12	3	4	1	12
	iii) Deviation from standard antibiotic prophylaxis.	3	4	1	12	3	3	1	9
	iv) Poor clinical correlation.	4	3	1	12	4	2	1	8
Follow up errors	i) Continuing Resistant drug	3	3	2	18	3	2	2	12
	ii) Lack of reviewing C/S reports.	2	4	2	16	2	4	2	16
	iii) IV to oral switch over.	1	3	3	9	1	2	3	6
Improper usage errors	i) Poor drug optimization.	3	3	1	9	3	2	1	6
	ii) Deviation from standard frequency setting.	3	3	2	18	3	2	2	12
	iii) Deviation from standard duration.	3	3	2	18	3	3	2	18
	iv) Poor justification.	3	3	2	18	3	2	2	12
Prescribing errors	i) Lack of review of antibiotic prescriptions.	3	3	1	9	3	1	1	3

Table 10: Control Phase-Type of Errors.

Type of error	No. of error	Percentage
Standard guideline error	5	41.67%
Prescribing error	2	16.67%
Follow-up error	1	8.33%
Improper usage error	4	33.33%

levels of 1.6, 2.6, 4.1 and 3.7 respectively which is described in the Figure 7.

Control phase

In the control phase, 100 patient data were collected for which a control chart (Figure 8) was prepared to evaluate the improvement in the major types of errors among which 5 (41.67%) Standard guideline errors, 2 (16.67%) Prescribing errors, 1 (8.33%) Follow up error and 4 (33.33%) Improper usage errors were identified and described in Table 10.

DISCUSSION

The prospective interventional study was conducted for a period of two years in a major trauma care centre. This study involved analyzing the efficacy of antimicrobial stewardship activities using six sigma DMAIC methodology which is similar to the study conducted by Monday LM *et al.* that explained about quality improvement stewardship intervention using lean six sigma improves patient care for community-acquired pneumonia.[13]

The study involved 2,250 patient data, out of which 1261 (50%) were male and 989 (43.9%) were female. Based on age distribution, the study involved 195 (8.6%) belonged to 0-15 age category, 1245 (55.33%) were from 16-60 age category and 810 (36%) were above the age of 60. The patient data had different co-morbidities which included diabetes, hypertension, CVD, endocrine disorders renal disorders tuberculosis, etc., and had been admitted for injury or disorders namely, polytrauma, amputation, infection, diabetic foot, THR, TKR, etc. The patient data with wound have been further categorized as clean, clean contaminated, contaminated and dirty. Several antibiotics had been used include amikacin, amoxicillin, cefuroxime, clindamycin, linezolid, vancomycin, meropenem, polymyxin B, etc. The antimicrobials usage pattern was grouped into prophylactic, empirical and specific usage based on the factors such as nature of wound, injury, culture reports, infections, etc.

In the Define phase, value stream mapping (Figure 3), SIPOC chart (Table 5), project charter (Table 6) and pareto chart (Figure 4) was developed which included title, clinical need, goal and scope of the project. A pareto chart was prepared with 100 patient data to evaluate the major type of errors that were standard guideline errors, prescribing errors, wrong antibiotic selection errors, follow up errors. From the Phase I, the standard guidelines errors were found to be 15 (44.12%), follow up errors were 6 (17.65%), improper usage errors were 3(8.82%) and prescribing errors were 10 (29.41%).

Followed by identifying errors, data collection form was generated to collect data from patient case sheets, HIS, patient interviews, local antibiogram and laboratory charts. Followed by Phase I, team moved to Phase II which was measure phase where 1025 patient data were collected among which 885 errors were detected. The defects per units (DPU), Defects Per Million

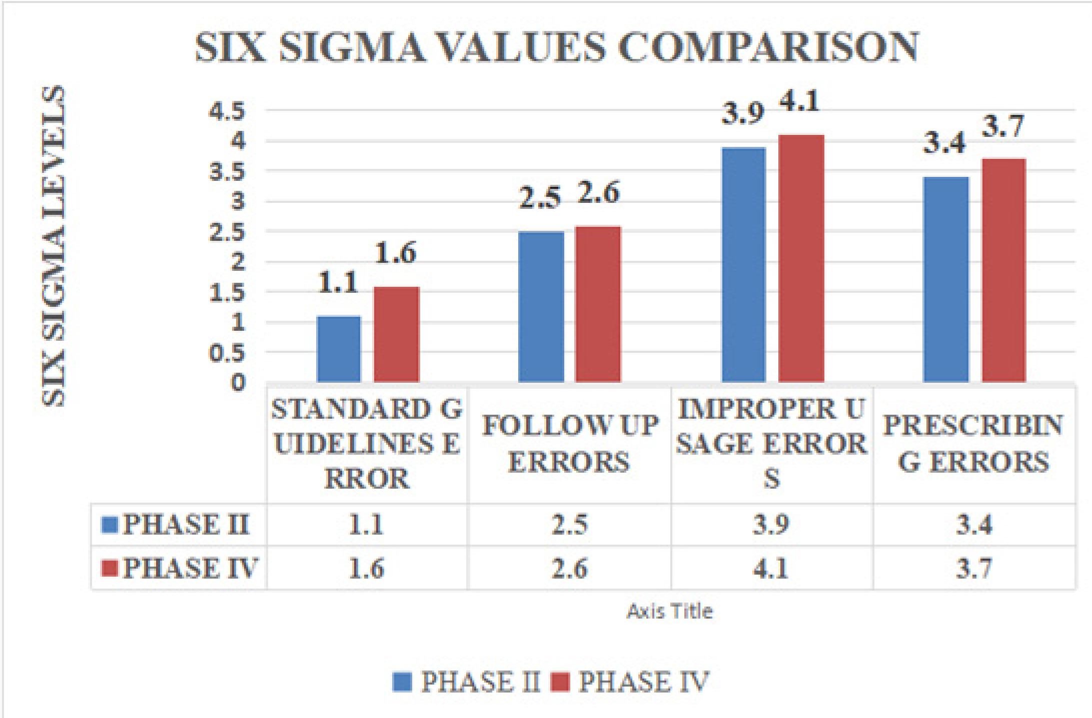

Figure 7: Comparison of six sigma levels.

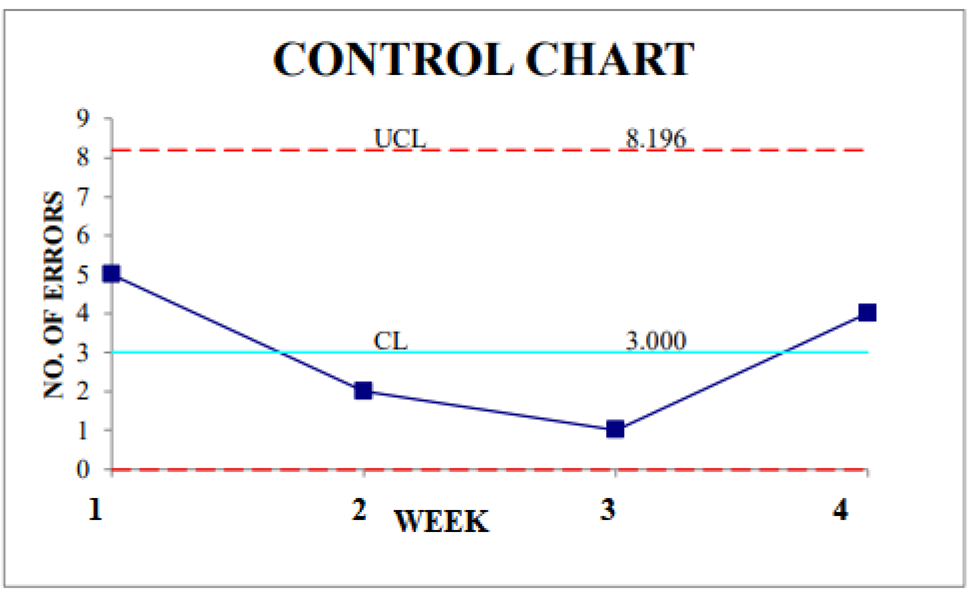

Figure 8: Control chart-Control phase.

Opportunities (DPMO) and corresponding sigma values of each error were calculated respectively.

Demonstration of root cause of errors using Failure Mode and Effect Analysis (FMEA) was done in Phase III (Analyze phase). Application of proposed action plan was implemented in Phase IV (Improve phase) in which about 1025 patient data were collected and further DPU, DPMO and corresponding sigma values of each error were calculated respectively.

The sigma values of Phase II (Measure phase) and Phase IV (Improve phase) were compared and marked increase in sigma levels were found which is significant in practical practice and thus supports the articles for Six Sigma practice.

In the control phase, 100 patient data were collected for which a control chart (Figure 8) was prepared to evaluate the improvement in the major types of errors among which 5 (41.67%) Standard guideline errors, 2 (16.67 %) Prescribing errors, 1 (8.33%) Follow up error and 4 (33.33%) Improper usage errors were identified.

The chronicle of Six Sigma commenced by Bill Smith who implemented Six Sigma at Motorola in 1986 with the goal of raising manufacturing quality. It was filed for trademark registration by Motorola in the early 1990s. Approximately two-thirds of Fortune 500 organizations had initiated Six Sigma programs by the late 1990s. Rosa A *et al.*[14] and Improta G *et al*[15] have initiated LSS in the healthcare system to reduce AMI rate and post COVID changes in patient management in the neurology and stroke unit respectively as a single centred study. Similarly, our study have initiated the implementation of six sigma in the field of antimicrobial stewardship as a single centered study to improve the antimicrobial usage pattern in healthcare sector and to lead the way for healthcare professionals concerned about the appropriate antimicrobial usage for a better future tomorrow.

CONCLUSION

Implementation of Six Sigma DMAIC methodology showed a marked reduction in guideline errors, irregular follow ups, improper antibiotic usage and prescribing errors. Correspondingly, the six-sigma level has improved from 1.1, 2.47, 3.87, 3.35 to 1.57, 2.55, 4.02 and 3.61 respectively. From the study, we identified the challenges in antibiotic stewardship, found the root causes and corresponding factors. The process was improved in Phase IV by implementing prepared action plans. This study helped in updating antibiotic policies in hospital setup. The study concluded that, by reducing antibiotic associated errors, problems such as usage of higher end antibiotics, excessive duration of use, improper use of it, poor clinical correlation of culture reports, cost of patient care can be reduced and that have direct impact on improving patient safety and clinical outcome. In conclusion, it is apparent that application of six sigma methodology is extremely useful in identifying, quantifying and measuring efficacy of healthcare processes in a complex hospital setup.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

ABBREVIATIONS

AMS: Antimicrobial stewardship; **CVD:** Cardiovascular disease; **DMAIC:** Define Measure Analyse Improve Control; **DPMO:** Defects per million opportunities; **DPU:** Defects per unit; **FMEA:** Failure mode and effect analysis; **HIS:** Hospital Information System; **ICMR:** Indian Council of Medical Research; **PK-PD:** Pharmacokinetics-Pharmacodynamics; **RPN:** Risk Priority Number; **RTI:** Respiratory tract infection; **SIPOC:** Supplier Input Process steps Output Customer; **THR:** Total hip replacement; **TKR:** Total knee replacement; **VSM:** Value stream mapping.

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