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Prediction Models for Patients with Arthroplasty: An Exploration of State-of-the-art

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Abstract

Arthroplasty is an operative procedure that involves remodeling, realignment and replacement of damaged surface of a bone with man-made, long-lasting material to reduce pain and restore function of a joint. The common arthroplasty surgery includes knee, hip and shoulder replacement. Surgical approaches used in arthroplasty are cemented, uncemented and hybrid joint prosthesis. The choice on the approach to deploy depends on the experience of the orthopedic surgeon and the patient physiology. Also, patient satisfaction after surgery, preoperative and postoperative requirements and duration of stay of a patient at the hospital depends on the deployed approach. The cost of the operation and medications depends on the approach and the duration of stay of the patient at the hospital. To ensure accuracy in the surgical approach to be deployed, pre and post operative requirements, and duration of stay of a patient in the hospital and a greater patient satisfaction after surgery, an efficient predictive model is required. Literature shows that, a number of prediction models have been proposed with the need for more ideal solutions. This paper presents the various prediction models in arthroplasty, taxonomy of arthroplasty, research gap and opportunities.

Keywords— Arthroplasty, operative procedure, knee, hip, shoulder, cemented prosthesis, uncemented prosthesis, operation cost, and predictive model

I. INTRODUCTION

Arthroplasty is an operative procedure that involves remodeling, realignment and replacement of damaged surface of a bone with man-made, long-lasting material to reduce pain and restore function of a joint. Common Arthroplasty surgery includes knee, hip and shoulder replacement [1]. Arthroplasty treats damages caused by osteoarthritis, rheumatoid arthritis, osteonecrosis, joint injuries, and so on from diseases. Surgical approaches used in arthroplasty are cemented, uncemented and hybrid joint prosthesis.

Advanced arthroplasty and pain in body joint have been immensely managed with both cemented and uncemented prosthesis. Arthroplasty with a prosthesis is one the most effective orthopedic surgeries for joint function recovery and pain reduction in patients affected by different pathologies especially osteoarthritis and osteonecrosis of femoral head and neck fractures [2]. Few months and a year after remodeling, realignment and replacement procedure, patients experienced less pain in the damaged part; nevertheless, some of them express dissatisfaction with their ability to carry out daily task, reduction in their ability to walk, long-term muscle weakness in some part of the body.

Arthroplasty may be performed using cemented or uncemented prosthesis. In cemented prosthesis, stability can be achieved earlier during the recovery process than the uncemented prosthesis. Geometric fitting, press-fit forces and friction between the bone and the implant are used to

achieve the primary implant stability while the secondary stability is achieved via ingrowths in the surface texture of the components. Despite the early stability achievement of the cemented prosthesis, the density of the bone around the prosthesis progressively decline due to decrease in mechanical stress, thereby resulting to high fracture risk [3]. Uncemented prosthesis uses press-fit to resurface and realign the fractured bone. The stratum of the bone immediate to the implant stem is preloaded and stimulated to grow [4]. Due to the periprosthetic feature of the uncemented prosthesis, the uncemented stem require more surgical revision few years after the surgery compared to the cemented ones. Also, the low quality of the adjacent bone to the implant stem makes the management of the fracture a formidable task to the surgeon [5]. However, both the cemented and uncemented prosthesis have similar risk of infection [6]. On the other hand, the post surgical revision received by uncemented implants achieve a greater success rate leading to less complications than the revision surgeries for cemented implant [7-9]. However, the overall survival rate of uncemented

prosthesis is marginally inferior to that of cemented prosthesis [10]. To recommend an uncemented prosthesis to a patient, the patient's bone quality must be accessed to determine the capability of the bone femur to resist press fitting and comprehensive stress during the surgery and subsequent functional loading. The ingrowths of the bone should be predictable. Presently, there exit no criterion for deciding on the surgical approach to deploy. Results from various studies have been obtained but a consensus has not yet been reached [9]. Surgeons have to decide on the approach to deploy based to the peculiar situation of the patient. The existing guidelines do not consider the measurable preoperative evaluations of bone quality despite their positive effects on the success of the surgery [10]. Cemented arthroplasty is commonly deployed in treating older, inactive and patients with weak bone as mineralization of bone diminishes with aging. Uncemented arthroplasty are commonly deployed in treating young and more physically active patients [11]. The probability of the need for surgical revision is directly proportional to patient age. Thus patients receiving implants at early age have greater possibility of requiring surgical revision and the prospect of intra operative fracture under press fitting as bone quality is minimal among that population [12, 13]. In decision making process of the surgical approach to deploy for a particular patient, bone and muscle quality are often considered. Today, clinics do not perform the preoperative routine of measuring bone and muscle quality, despite their influence on the outcome of the surgery.

The choice of the approach to adopt depends on the experience of the orthopedic surgeon and the patient

physiology. Also, patient satisfaction after surgery, preoperative and postoperative requirements and length of stay of a patient at the hospital depends on the deployed approach. The cost of the operation and medications depends on the approach and the length of stay of the patient at the hospital. To ensure accuracy in the surgical approach to be deployed, preoperative requirements, surgical outcome, and length of stay of a patient in the hospital and improve patient satisfaction after surgery, an efficient predictive model is required.

Various numbers of predictive models for length of stay of patient at the hospital, payment model, functional outcome, patient expectation e.t.c. have been proposed by researchers with the need for more ideal solutions. This paper presents the various predictive models used in arthroplasty, overview and taxonomy of arthroplasty, research gap and opportunities.

This paper is structured as follows: chapter one contains introduction, chapter two present an overview of arthroplasty, chapter three presents the summary of various predictive models used in arthroplasty, chapter four presents research gap and research opportunities and chapter five concludes the survey..

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II. Overview of Arthroplasty

Arthroplasty is an operative procedure that involves remodeling, realignment and replacement of damaged surface of a bone with man-made, long-lasting material to reduce pain and restore function of a joint. Common Arthroplasty surgery includes knee, hip and shoulder replacement [1]. Arthroplasty treats damages caused by osteoarthritis, rheumatoid arthritis, osteonecrosis, joint injuries, and so on from diseases.

A. Arthroplasty Surgery Approach

Arthroplasty is divided into cemented and uncemented prosthesis. Cemented prosthesis uses poly-Methyl-Meth-acrylate (PMMA) to serve as a grout, producing an interlocking fit between cancellous bone and prosthesis. Uncemented hips rely on biological fixation of bone to a surface coating on the prosthesis. Initial fixation is achieved by inserting prosthesis slightly larger than the prepared bone-bed, generating compression hoop stresses, and obtaining a so-called press-fit [39].

B. Arthroplasty Taxonomy

In this section we present the taxonomy of arthroplasty from the surgeon and the patient perspective. The taxonomy is based on surgery type, cost of surgery and medication for the period of stay at the treatment center, patient satisfaction after surgery, number of surgical revision after initial surgery, length of stay of the patient, implant stability, fracture risk and complications associated with the surgery

C. Comparison of Arthroplasty Surgical Approach

In this section we compare the two arthroplasty surgical approach: cemented and uncemented prosthesis based on the materials used, length of stay of patient, surgical revision, cost, fracture risk, complications e.t.c.

Fig 1: Arthroplasty taxonomy

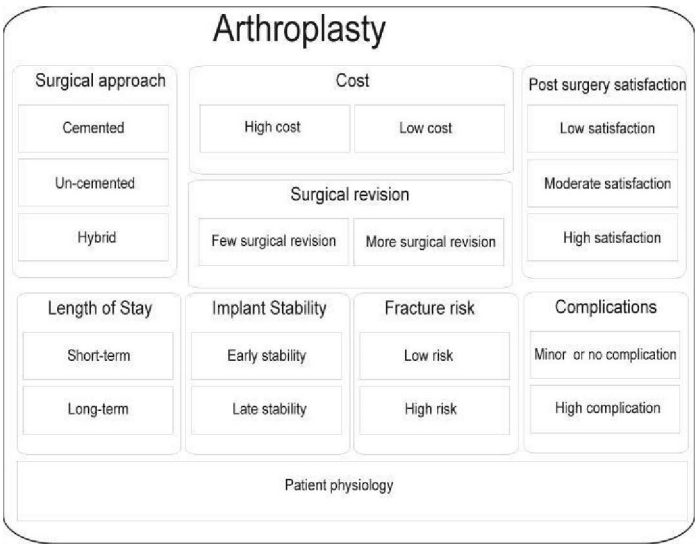

TABLE I. COMPARISON OF CEMENTED AND UNCEMENTED PROSTHESIS.

Parameter	**Cemented Prosthesis**	**Uncemented Prosthesis**
Material used	Poly Methyl Meth Acrylate (PMMA)	Bone
Stability	Earlier stability in recovery process	Late stability in recovery process
Surgical revision	Few revisions	More revisions
Fracture risk	Increased fracture risk	Low fracture risk
Risk of infection	Equal risk of infection	
Management of fracture	Less difficult	Difficult
Success rate	Less success rate	Higher success rate
Complications	More complications may occur	Few complications
Survival rate		Marginally inferior
Patients category	Older aged and weak bone patients	Young aged patients

III. Predictive Models for Arthroplasty

Today, orthopedic surgeons are more concerned about the surgical approach to deploy in treating patients, minimizing risk of fracture, infections, complications and number of surgical revisions while the patients are more concerned about the length of stay at the hospital, outcome of the surgery, financial implication of the surgery and medication. Scientist in the field of computing have proposed numerous prediction models that using Machine Learning and Deep Learning algorithms to predict the length of stay, surgical approach, financial implication and other requirements for patients needing arthroplasty.

In this section we explore different prediction models in arthroplasty along with the prediction parameters and the surgical stage the model is applied.

A. Prediction Model for Surgical Approach

The decision on whether to employ cemented or uncemented approach depends on the patient physiology and associated chronic condition. Parameters like age, bone and muscle quality, associated chronic conditions e.t.c influence the decision on the surgical approach. Prediction model for surgical approach consider the above parameters of a patient and predict a suitable approach for the patient's joint function recovery. The approach used determines the patient length of stay at the hospital.

B. Prediction model for Length of Stay

Patient length of stay is the total time to be spent by a patient under arthroplasty. Length of stay prediction model uses parameters like age, gender, associated chronic conditions, comorbidity status, APR severity of illness, type of admission, number of associated diagnosis e.t.c to predict the time frame from admission to discharge. This model is usually applied upon admission of the patient at the hospital. Surgical approach is one of the most important factors to determine the patient length of stay.

C. Risk Prediction Model

The risk prediction model predicts the outcome of the surgery. Outcome of the surgery depends on the approach used, associated chronic condition and complications. The risk and outcome of the surgery is one of the concerns of both the surgeon and the patient. Therefore an efficient prediction model is highly required.

D. Cost Prediction Model

The financial implication for arthroplasty varies among patients. Patient is charged according to the type of surgery and length of stay of patient at the hospital. The surgical approach is determined by the parameters in prediction models for surgical approach and the length of stay of patient is determined by the parameters of the prediction model for length of stay. This implies that the basic parameters for cost prediction model are surgical approach and length of stay. In addition, complication encountered after surgery may be included. The cost prediction model is a model that predicts the financial implication of arthroplasty surgery and medication given to patient prior to stability.

IV. Summary of Prediction Models in Arthroplasty

In this section, we present the summary of prediction models proposed by researchers in their research work. The summary consists of the methodology or algorithm proposed, prediction model (surgical approach, length of stay, risk/outcome of the surgery), types of operation based on the location of the surgery (Total knee, total hip or total shoulder).

S/no	Author & Year	Method/Tool Used	Prediction Model				Type of Operation based on Location		
			Surgical Approach	Length of Stay (LoS)	Risk/Outcome Prediction	Cost	Total Knee Arthroplasty (TKA)	Total Hip Arthroplasty (THA)	Total Shoulder Arthroplasty (TSA)
1.	Anis. H. K. et al., 2020 [14].	Personalized outcome prediction tool using regression	NA	NA	Yes	NA	Yes	NA	NA
2.	Ramkumar, P. N. et al., 2019 [15]	Artificial Neural Network (ANN)	NA	Yes	NA	Yes	NA	Yes	NA
3.	Ricciardi, C. et al., 2020 [2]	Image processing analysis technique and Machine Learning	Yes	Yes	Yes	NA	NA	Yes	NA
4.	Tolk, J. J. et al. , 2020 [16]	Multivariable logistic regression analyses	NA	NA	Yes	NA	Yes	NA	NA
5.	Slaven, E. J. et al., 2012 [17]	Classification and regression tree (CART) analyses and logistic regression	NA	NA	Yes	NA	Yes	NA	NA
6.	Liu, J et al, 2021 [18]	Linear regression and multivariate logistic regression	NA	NA	Yes	NA	Yes	NA	NA

7.	Venäläinen, M. S. et al., 2021 [19]	Multivariable Lasso regression	NA	NA	Yes	NA	NA	Yes	NA
8.	Simmen, B. R. et al., 2008 [20]	Logistic regression model	NA	NA	Yes	NA	NA	NA	Yes
9.	Alshahwani, A. A. et al., 2021 [21]	Risk assessment and prediction tool	NA	Yes	NA	NA	Yes	Yes	NA
10.	Halawi, M. J. et al., 2015 [22]	Multivariable logistic regression model	NA	Yes	NA	NA	NA	Yes	NA
11	Karhade, A. V. et al., 2019 [23]	Stochastic gradient boosting (SGB), Random Forest, Support Vector Machine (SVM), Neural Network, and Elastic-net Penalized Logistic Regression (ENPLR)	NA	NA	Yes	NA	NA	Yes	NA
12.	Karnuta, J. M. et al., 2020 [24]	Neural Network	NA	Yes	Yes	Yes	NA	NA	Yes
13.	Oosting, E. et al., 2015 [25]	Risk Assessment and Predictor Tool (RAPT) and Performance-based Functional Tests	NA	NA	Yes	NA	NA	Yes	NA

14.	Petis, S. M. et al., 2016 [26]	Logistic regression	NA	Yes	Yes	NA	NA	Yes	NA
15.	Li, Y. et al., 2021 [27]	Random Survival Forest (RSF) algorithm	NA	NA	Yes	NA	NA	Yes	NA
16.	Kugelman, D. N. et al., 2021 [40]	XGBoost (eXtreme Gradient Boosting)	NA	Yes	Yes	NA	NA	Yes	NA
17.	Ramkumar, P. N. et al., 2019[28]	Naïve Bayesian Model	NA	Yes	Yes	Yes	NA	Yes	NA
18.	Baessler, A. M. et al., 2021 [29].	Pair wise analysis, Linear Regression	NA	NA	Yes	NA	NA	NA	Yes
19.	**V.** SNIDERMAN, J. ET AL., 2021 [30]	Least Absolute Shrinkage Selection Operator (LASSO)	NA	NA	Yes	NA	NA	Yes	NA
20.	**VI.** GABRIEL, R. A. ET AL., 2019 [31]	Multivariable logistic regression, Point based calculator	NA	NA	Yes	NA	NA	Yes	NA
21.	Kumar, V. et al., 2021 [32].	XGBoost machine learning technique	NA	NA	Yes	NA	NA	NA	Yes

22.	Polce, E. M. et al., 2021 [33]	stochastic gradient boosting, Random Forest, Support Vector Machine, Neural Network,and Elastic-net Penalized Logistic Regression	NA	NA	Yes	NA	NA	NA	Yes
23.	Chen, R. E. et al., 2019 [34].	Patient-Reported Outcomes Measurement Information System (PROMIS)	NA	NA	Yes	NA	NA	NA	Yes
24.	Dacombe, P. et al., 2020[35].	Simple descriptive statistical analysis using Microsoft Excel	NA	NA	Yes	NA	NA	NA	Yes
25.	Sivasundaram, L. et al, 2019 [36]	Multivariable logistic regression	NA	NA	Yes	NA	NA	NA	Yes
26.	Gronbeck, C. J. et al., 2019 [37].	Multivariable logistic regression	NA	NA	Yes	NA	NA	Yes	NA
27.	Kim, K. Y. et al., 2018 [38].	Outpatient Arthroplasty Risk Assessment (OARA)	NA	Yes	Yes	NA	NA	Yes	NA

As can be seen in figure 2 above 65% of the models focused on risk and outcome of the surgery, 24% focused on length of stay of patient, 8% focused on the financial implication of the operation and medication and 3% focused on prediction of surgical approach. Also, figure 3 shows that 17.9% of the models used data on total knee arthroplasty, 53.6% used data on total hip arthroplasty and 28.6% used data on total shoulder arthroplasty

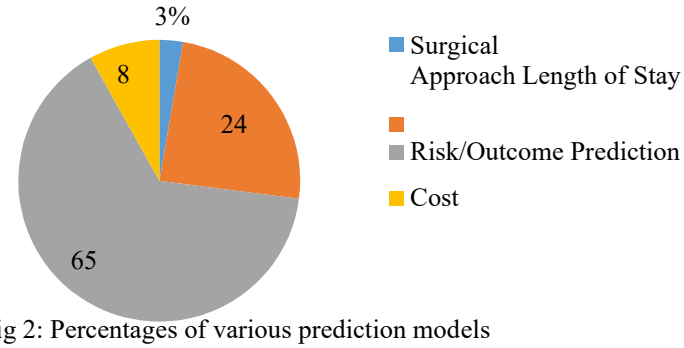

Fig 2: Percentages of various prediction models

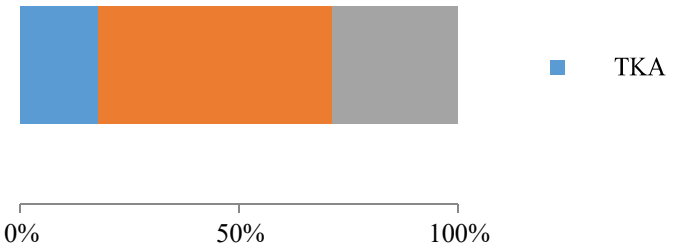

Fig 3: Percentages of operation type based on body location

VII. Research Gap and Opportunities

Based on the summary in table 2, it is proved that there are few prediction models for predicting surgical approach which forms the basis for other prediction models like outcome of the surgery, length of stay of a patient and cost of the surgery and medication. Development of efficient prediction models for surgical approach that will take into account of parameters like age, gender, underlying issues
e.t.c. will be a great research opportunity.

Literature review shows that there is no single model or tool for the prediction of surgical approach, outcome of the surgery, length of stay and cost of the surgery and medication. Developing a single model for the prediction of surgical approach, outcome of the surgery, length of stay of the patient, and the cost of the surgery will be another great research opportunity.

VIII. Conclusion

This survey explores the various prediction models in arthroplasty, the basic parameters associated to the prediction models and the objectives of the models. It is proved that 65% of the models focused on risk and outcome of the surgery, 24% focused on length of stay of patient, 8% focused on the financial implication of the operation and medication and 3% focused on prediction of surgical approach. Also, 17.9% of the models use data on total knee arthroplasty, 53.6% use data on total hip arthroplasty and 28.6% use data on total shoulder arthroplasty. Based on the literature, it is proved that there are few prediction models for predicting surgical approach which forms the basis for other prediction models and there is no single model or tool for the prediction of surgical approach, outcome of the surgery, length of stay and cost of the surgery and medication.

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