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## Neuroprotection by dipeptidyl-peptidase-4 inhibitors and glucagon-like peptide-1 analogs *via* the modulation of AKT-signaling pathway in Alzheimer's disease

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### Abstract

Alzheimer's disease (AD) is the most common reason for progressive dementia in the elderly. It has been shown that disorders of the mammalian/mechanistic target of rapamycin (mTOR) signaling pathways are related to the AD. On the other hand, diabetes mellitus (DM) is a risk factor for the cognitive dysfunction. The pathogenesis of the neuronal impairment caused by diabetic hyperglycemia is intricate, which contains neuro-inflammation and/or neurodegeneration and dementia. Glucagon-like peptide-1 (GLP1) is interesting as a possible link between metabolism and brain impairment. Modulation of GLP1 activity can influence amyloid-beta peptide aggregation *via* the phosphoinositide-3 kinase/AKT/mTOR signaling pathway in AD. The GLP1 receptor agonists have been shown to have favorable actions on the brain such as the improvement of neurological deficit. They might also exert a beneficial effect with refining learning and memory on the cognitive impairment induced by diabetes. Recent experimental and clinical evidence indicates that dipeptidyl-peptidase-4 (DPP4) inhibitors, being currently used for DM therapy, may also be effective for AD treatment. The DPP-4 inhibitors have demonstrated neuroprotection and cognitive improvements in animal models. Although further studies for mTOR, GLP1, and DPP4 signaling pathways in humans would be intensively required, they seem to be a promising approach for innovative AD-treatments. We would like to review the characteristics of AD pathogenesis, the key roles of mTOR in AD and the preventive and/or therapeutic suggestions of directing the mTOR signaling pathway.

**Key Words:** Alzheimer's disease; Cognitive disorder; Dementia; Glucagon-like peptide-1; Dipeptidyl peptidase-4; Mammalian/mechanistic target of rapamycin

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**Core Tip:** Disorders of mammalian/mechanistic target of rapamycin (mTOR) signaling pathways are related to Alzheimer's disease (AD). Although further studies for mTOR, glucagon-like peptide-1, and dipeptidyl-peptidase-4 signaling are needed, they seem to be a promising approach for innovative AD-treatments.

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## INTRODUCTION

Alzheimer's disease (AD) is a chronic neuro-degenerative disease of the central nervous system (CNS), which is described by a slow and unremitting pathology[1]. The chief clinical appearance of AD is progressive continuing dementia, which is categorized by intellectual symptoms such as diminished cognition, memorial dysfunction, and behavioral complaints[2]. The prevention of AD is a public health concern because of a lack of effective treatments. The onset of AD is associated with an increase in age and to a reduction in mitochondrial ATP synthesis in the hippocampus of the brain[3]. Estrogen has a neuro-protective effect on various nerve cells, however, estrogen also has a carcinogenic effect to non-nerve proliferating cells[4]. Pre-diabetic risk factors, obesity, and metabolic syndrome could promote cognitive dysfunction[5]. Neuro-pathological features of AD are neurofibrillary tangles, molded by hyper-phosphorylated tau protein, which may accumulate into oligomers and/or amyloid plaques[6]. There might be an association between metabolism and brain function. Insulin works as a pro-survival neurotrophic factor with its receptors at cognitive areas in the brain[7]. The commonalities have been found between AD and type 2 diabetes mellitus, which is believed as a high-risk factor for AD[8]. In addition, the animal studies have shown that GLP1 may benefit on the neuro-degeneration[9]. The GLP1 receptor agonists have also been shown as possessing neuro-protective effects in AD, which seem to improve nearly all neuro-pathological features as well as cognitive functions of AD[10]. For example, neurofibrillary tangles, amyloid plaques, and neuro-inflammations in the hippocampus have been reduced in AD model mice[11,12]. In the rat model, it has been shown that a GLP1 receptor agonist also prevents synaptic damage induced by amyloid-beta accumulation, which supports the spatial memory by affecting the phosphoinositide-3 kinase (PI3K)-AKT pathway[11]. Targeting dipeptidyl-peptidase-4 (DPP4) inhibitors that is involved in the GLP1 signaling has been considered as promising therapeutic models to AD[13]. Furthermore, mammalian/mechanistic target of rapamycin (mTOR) has been considered as a center that integrates multiple signaling cascades including the GLP1 receptor signaling, which may also be involved in the progression of AD[14]. We will review the several studies linking potential protective factors to pathogenesis of AD, focusing on the roles of GLP1 and DPP4 inhibitors in the PI3K/AKT/mTOR pathway. In addition, we will summarize the recent researches of the AD-associated biology, by which several diet factors could relate to the pathway. To overview the potential physical activities through the PI3K/AKT/mTOR signaling may contribute to the preventive and/or therapeutic strategy for AD.

## PI3K/AKT/MTOR SIGNALING IS INVOLVED IN NEUROPROTECTION OF AD

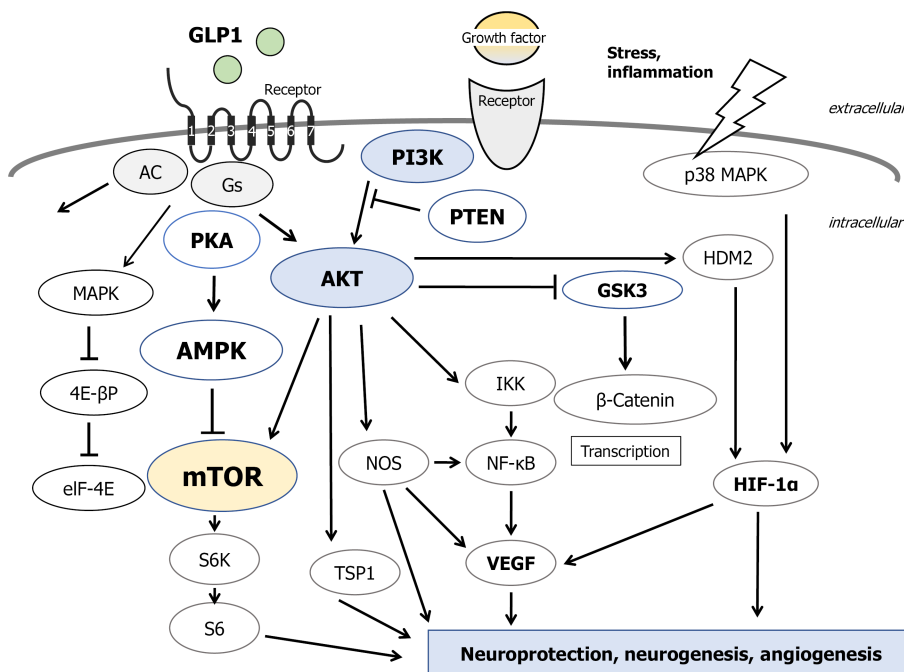
The mTOR plays a significant role in diverse cellular processes including cell survival, cell proliferation, and cell death[15], which is a particular molecule bound to rapamycin. The rapamycin is an immune-suppressant used for the anti-rejection of tissue-transplantation[16]. Rapamycin also exhibits remarkable potential in the fields of neuro-protection, anti-aging, *etc.*[17]. It can inhibit the activity of the mTOR[18]. The mTOR is also a nutrient-sensor that mediates the signaling responses to energy status

in a cell[19]. Besides, the mTOR activity could be inhibited by nutritional signaling such as caloric restriction[20]. Inhibition of the mTOR could alter cellular responses from cell proliferation to cell quiescence with decreased protein synthesis[21]. Basically, mTOR-inhibition has been shown to increase resistance to stresses resulting in the regulation of age-related diseases, which may contribute to the extension of total life-time[22]. Modulation of the mTOR-function to inhibit cellular apoptosis is deeply involved in the protective effects of pharmacologic agents aiming against diabetes and neurodegenerative diseases[23]. The mTOR activation inhibits autophagy, which is often disrupted in age-related diseases[24]. In the mouse brain neurons, amyloid-beta oligomers have been thought to activate the JNK signaling, leading to insulin resistance[25]. Instead, activation of the PI3K/AKT signaling pathway could bring the inhibition of apoptosis cascade including caspase-signaling[26], leading to the inhibition of the induction of inflammatory cytokines[27]. Following the activation of growth-factor receptors with their ligand, PI3K/AKT gets activated directing to promotion of mitogen-associated protein kinase/extracellular signal-regulated kinases and mTOR[28]. On the other hand, adenosine monophosphate-activated protein kinase (AMPK) is an important signaling mediator of GLP1 receptor, which inhibits mTOR[29]. In fact, the AMPK-loss has resulted in hyper-proliferation and hyperactive mTOR signaling[30].

Therefore, the mTOR signaling could interact with several upstream components including PI3K/AKT and AMPK[31] (Figure 1). Increasing studies have established the involvement of the mTOR signaling in various neuro-degenerative diseases including AD[32]. In particular, activated mTOR signaling is a contributor to the progression of AD[33]. Furthermore, there is a close relationship between mTOR signaling and the presence of amyloid-beta plaques and cognitive impairment[34]. So, the development of mTOR-inhibitors may be useful for the prevention and treatment of AD and/or the other neuro-degenerative diseases. In the CNS, inhibition of the mTOR has been revealed to protect vascular functions in aging[35]. Appropriate dose of rapamycin may diminish neurofibrillary tangles and amyloid-beta plaques improving cognitive functions in AD model mice[36]. Similarly, mTOR inhibition without malnutrition is able to improve the pathology of AD[37]. Moreover, mTOR inhibition protects mitochondrial function, reduces oxidative stress, and maintains glucose homeostasis in aging[20,38]. Conversely, activation of the mTOR may shift metabolisms toward ketone-body consumption[39]. Elevated ketone-body metabolisms and/or the administration of the ketogenic diet have been shown neuro-protective against aging, neurodegeneration, and AD[40].

## GLP1 AND DIPEPTIDYL PEPTIDASE-IV-INHIBITION EXHIBITS NEUROPROTECTIVE EFFECTS IN AD

GLP1 is an endogenous hormone secreted from intestinal L-cells in response to food-intake[41]. Proteolytic cleavage of the precursor GLP1 (1-37) produce two biological active forms[42]. GLP1 may stimulate insulin-secretion from beta-cells in pancreatic islets under hyperglycemic situations and may decrease glucagon secretion from alpha-cells in pancreatic islets[43]. Signal transduction of GLP1 is mediated by the GLP1 receptor, a G-protein coupled seven-pass-transmembrane domain receptor, heading to cyclic adenosine monophosphate dependent activation of protein kinase A and AMPK. In fact, it has been shown that GLP1 receptor agonists-treatment activates the AMPK signaling within myoblast C2C12 cells[44]. On the contrary, the GLP1 receptor may also operate the downstream signal transduction from the PI3K/AKT pathway so as to work against cellular apoptosis[45]. Accordingly, the GLP1 receptor could dually modulate the activity of mTOR, a key kinase regulating proliferation, survival, and protection in balance. Actually, GLP1 receptor antagonists also stimulate insulin activation by the PI3K/AKT signaling pathway, with the following activation of mTOR and inhibition of GSK3-beta, an essential kinase involved in the phosphorylation of tau protein in AD[46]. GLP1 may also be involved in the regulation of autophagy, the reduction of the oxidative stress, and in the protection of CNS with induction of anti-inflammatory signaling[47]. In addition, GLP1 plays a critical role preventing cardiovascular diseases, in which GLP1 and its analogs may contribute a great deal in the treatment of the diseases[48]. Likewise, it has been shown that GLP1 receptor agonists reduce the infarct size, inflammation, and apoptosis in a rat model of stroke[49].



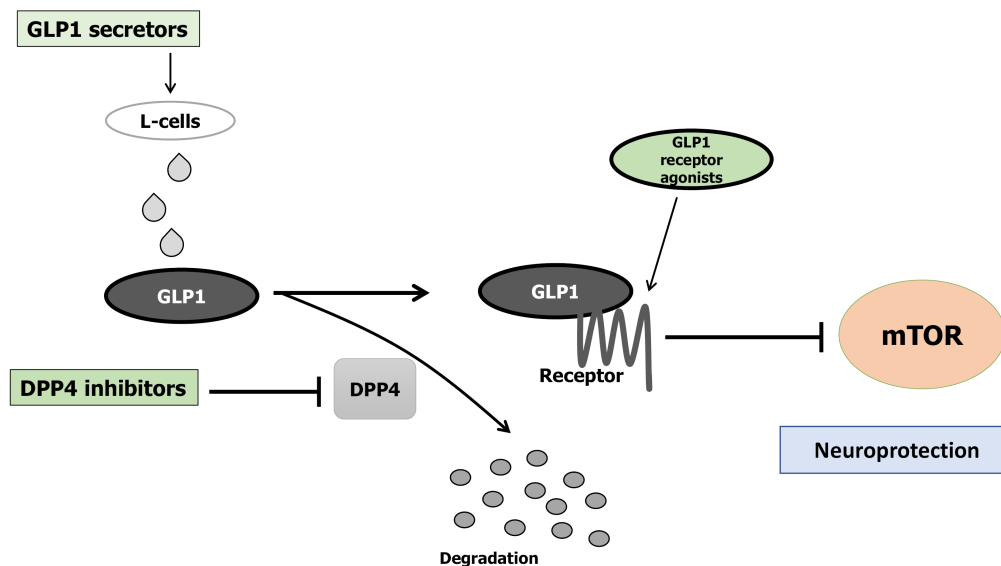
**Figure 1** Several modulator molecules linked to the phosphoinositide-3 kinase/AKT/mammalian/mechanistic target of rapamycin signaling in an extracellular growth-factor response are demonstrated. Example molecules known to act on the glucagon-like peptide-1 (GLP1)-receptor/adenosine monophosphate-activated protein kinase (AMPK)/mammalian/mechanistic target of rapamycin (mTOR) signaling pathway are also shown. Note that some critical events such as immune activation and/or cytokine-induction have been omitted for clarity. Arrowhead means stimulation whereas hammerhead represents inhibition. PI3K: Phosphoinositide-3 kinase; PKA: Protein kinase A; PTEN: Phosphatase and tensin homologue deleted on chromosome 10; DPP4: Dipeptidyl-peptidase-4; GSK3: Glycogen synthase kinase 3; MAPK: Mitogen-activated protein kinase; S6K: S6 kinase; AC: Adenylate cyclase; Gs: Stimulatory G-protein; eIF-4E: Eukaryotic translation initiation factor 4E; TSP1: Thrombospondin-1; VEGF: Vascular endothelial growth factor; NOS: Nitric oxide synthase; IKK: I kappa B kinase; NF-κB: Nuclear factor-kappa B; HDM2: Human double minute 2; HIF-1α: Hypoxia inducible factor 1-alpha.

GLP1 is rapidly degraded by DPP4, a serine aminopeptidase expressed in various organs including brain, pancreas, liver, and gut[50]. Therefore, inhibitors of DPP4 may prolong the bioactive half-life of GLP1 in the circulation, which is additionally effective in amending hyperglycemia[51]. The DPP4 inhibitor, linagliptin, has been shown to protect neurons against amyloid beta-induced cytotoxicity and tau hyperphosphorylation by restoring insulin downstream signaling in AD[52]. Furthermore, the linagliptin alleviated amyloid-beta-induced mitochondrial dysfunction and intracellular ROS generation by a mechanism involving the activation of AMPK-Sirt1 signaling pathway[53]. Chronic administration of another DPP4 inhibitor, sitagliptin, in AD model mice is associated with increased levels of brain GLP1, reductions in the inflammation-biomarkers, and reduction of amyloid-beta deposition in a dose dependent manner[54,55]. Significant reduction in amyloid-beta-42 Level has been associated with the use of linagliptin implying potential application in AD[56]. Also, linagliptin improved vascular functions by increasing creation of nitric oxide and restraining concentration of apolipoprotein B[56]. DPP4 inhibitors can block the DPP4 to diminish GLP1-degradation, prolong GLP1 active life-time, and sensitize insulin-activity for the aim of lowering hyperglycemia[57], and for neuro-protection (Figure 2).

GLP1 and various DPP4 inhibitors (linagliptin, sitagliptin, saxagliptin, *etc.*) seem to be related to their ability to rescue the insulin cascade. Brain insulin signaling has been reported to dwindle with age[58]. So, restoring insulin signaling might be advantageous to patients with AD. Amazingly, intranasal insulin administration, improves memory in healthy adults without affecting circulating levels of insulin and/or glucose[59-61]. In addition, intranasal insulin improves cognitive performance in patients with early AD[59]. It is possible that therapeutic options for AD arise from this mechanism improving for neural insulin-resistance by the DPP4 inhibitors.

## DIET WITH CERTAIN KINDS OF NATURAL PRODUCTS MAY IMPROVE AD

Potential preventive factors against AD including lifestyle factors have been suggested to be neuro-protective by epidemiological research[62]. In particular, diet could play a



**Figure 2** Implication of decreased dipeptidyl-peptidase-4 activity, increased Glucagon-like peptide-1, increased Glucagon-like peptide-1-receptor agonists, and decreased mammalian/mechanistic target of rapamycin activity for the neuroprotection. Arrowhead means stimulation whereas hammerhead represents inhibition. Note that some critical pathways have been omitted for clarity. GLP1: Glucagon-like peptide-1; mTOR: Mammalian/mechanistic target of rapamycin; DPP4: Dipeptidyl-peptidase-4.

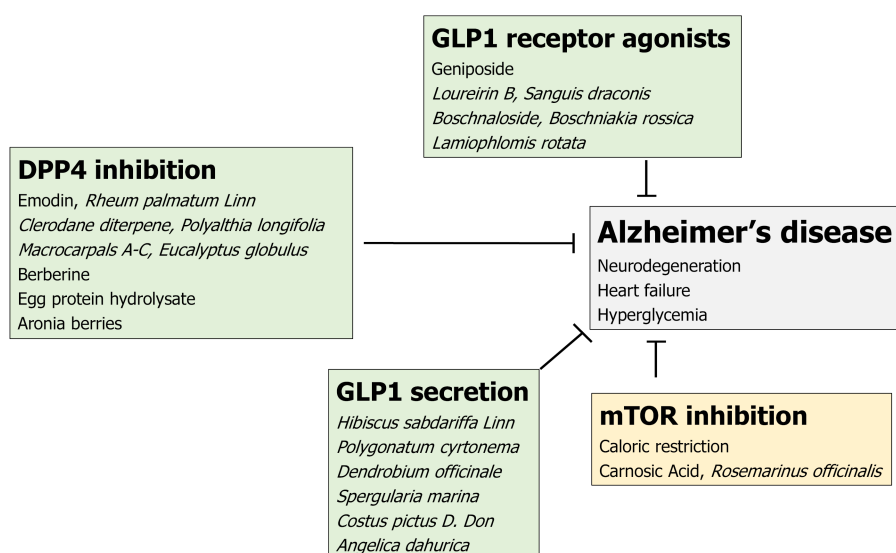
key role in the neuro-protection of AD[63]. However, the epidemiological analysis of the relations between nutrient and neuroprotection is very intricate. In addition, we think it unlikely that a single component plays a major role in the neuro-protection. The complexity of the human diet and synergistic and/or antagonistic effects among the various nutrients and food ingredients make it more difficult to examine their distinct effects. However, natural products from several plants and animal sources have been used as good preventive factors against AD through different mechanisms and analytical techniques. Here, we partially summarize them in a view point of mTOR inhibition, GLP1 receptor agonists, GLP1 secretion, and DPP4 inhibition. (Figure 3).

First of all, dietary restriction elicits cell protective responses in nearly all cells and tissues including nerve-cells and brain, which could conduct to activation of SIRT1 and inhibition of mTOR and S6K in C57BL/6 mice[64]. Carnosic acid, a polyphenolic diterpene isolated from the herb rosemary (*Rosmarinus officinalis*) can inhibit the activity of mTOR[65].

Next, GLP1 receptor agonists could protect neurons. Currently, diabetes mellitus treatment based on GLP1 work is being developed. Geniposide, an iridoid glycoside extract from the gardenia fruit, is used in traditional Chinese medicine to alleviate symptoms of liver and inflammatory diseases[23,66]. Geniposide modulates GLP1 receptors signaling[66]. Loureirin B is a natural product derived from *Sanguis draconis*, which promotes insulin secretion of Ins-1 cells through GLP1 receptor[67]. *Lamiophlomis rotata* is an orally available Tibetan herb, which specifically reduces pain hypersensitivity states through the activation of GLP1 receptors[68]. Boschnalioside is the major iridoid glycoside in *Boschniakia rossica*, a well-known traditional Chinese medicine, which can interact with the extracellular domain of the GLP1 receptor[69].

As for compounds stimulating the GLP1 secretion, the ingredient of *Hibiscus sabdariffa* Linn can increase GLP1 secretion in the ileum[70]. *Polygonatum cyrtoneura* polysaccharide stimulates GLP1 secretion from enteroendocrine cells[71]. Polysaccharides from the stems of *Dendrobium officinale* can decrease fasting blood sugar levels by stimulating GLP1 secretion[72]. *Spergularia marina* can induce GLP1 secretion, which is a halophyte that grows in mud flats[73]. *Costus pictus* D. Don, commonly known as insulin plant, is a traditional Indian antidiabetic herbal medicine, which acutely stimulates GLP1 secretion from intestinal L-cells[74]. *Angelica dahurica* extracts can improve glucose tolerance through the GLP1 secretion[75].

Finally, the intensive search for DPP-4 inhibitors in plant materials has resulted in the identification of macrocarpal A-C from *Eucalyptus globulus* as a potent inhibitor of DPP4[76]. Furthermore, a variety of other plant derived compounds have been reported to be DPP4 inhibitors. For example, emodin, a natural compound from *Rheum palmatum* Linn, inhibits DPP4 activity in a dose-dependent manner[77].



**Figure 3** Simplified diagrams indicating the biochemical properties of several natural products are shown. Several herbs and/or their ingredients may contribute to the neuroprotection against the progression of Alzheimer's disease. Hammerhead represents inhibition. DPP4: Dipeptidyl-peptidase-4; GLP1: Glucagon-like peptide-1; mTOR: Mammalian/mechanistic target of rapamycin.

Clerodane diterpene can potentiate hypoglycemia *via* the inhibition of DPP4[78]. Short-term berberine administration can decrease plasma glucose levels through local inhibition of intestinal DPP4[79]. Long-term supplementation with the egg protein hydrolysate exhibits mild *in vivo* DPP4-inhibitory activities[80]. Furthermore, DPP4 is significantly inhibited by cyanidin 3,5-diglucoside present in aronia berries juice[81].

## PERSPECTIVES

It is clear that AD may be a multifactorial and incurable disease. Current treatment strategies against AD are mainly directed at reducing amyloid-beta development and inhibiting amyloid-beta aggregation *via* the mechanisms including secretase-inhibition and/or impeding tau hyper-phosphorylation[82]. However, medical trials seem to have failed to demonstrate their significant efficacy without any severe side-effects in clinical situations. Since diet with natural products involved in GLP1 signaling, introduced here, are considered safe for long-term use, they could be an encouraging therapeutic approach against AD. In particular, they could exhibit a lower hypoglycemia risk in comparison to other anti-diabetic medications. On the other hand, GLP1 analogues have been found to decrease appetite. It was noticed that pyramidal neurons of the hippocampus and Purkinje cells of the cerebellum have expressed with GLP1 receptor[83]. In addition, several research reports support extra-pancreatic actions of GLP1 and its analogs by crossing the blood brain barrier (BBB), which are independent of its actions on glucose regulation[84]. AD could be considered as a brain disorder that appears to have fused features of insulin deficiency and insulin resistance. Consequently, DPP4 inhibition, GLP1 secretion, GLP1 receptor agonists, and/or mTOR inhibition may all be effective towards the treatment of AD as well as the other neurodegenerative diseases. This approach might accept new targets with simultaneously multiple molecular mechanisms with minimal side effects. Evaluation for intensive experiments should be provided to obtain further insights. Also, long-term studies are mandatory to clarify its efficacy and safety for the treatment of AD as a brain disorder.

## CONCLUSION

Current treatment strategies against AD are directed mainly at reducing amyloid-beta development and inhibiting amyloid-beta aggregation *via* the mechanisms including secretase-inhibition and/or impeding tau hyper-phosphorylation. However, medical trials seem to have failed to demonstrate their significant efficacy without any severe side-effects in clinical situations. Since diet with natural products involved in GLP1



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# Remission is not maintained over 2 years with hematopoietic stem cell transplantation for rheumatoid arthritis: A systematic review with meta-analysis

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## Abstract

### BACKGROUND

Hematopoietic stem cell (HSC) transplantation (HSCT) is being accepted as a standard of care in various inflammatory diseases. The treatment of rheumatoid arthritis (RA) has been closely evolving with the understanding of disease pathogenesis. With the rising resistance to the traditional disease-modifying anti-rheumatic drugs and targeted biological therapy, researchers are in pursuit of other methods for disease management. Since the ultimate goal of the ideal treatment of RA is to restore immune tolerance, HSCT attracts much attention considering its reparative, paracrine, and anti-inflammatory effects. However, a systematic review of studies on HSCT in RA is lacking.

### AIM

To investigate the role of HSCT in the management of RA.

### METHODS

A detailed search of PubMed, Scopus, EMBASE, Cochrane, and the Web of Science databases was made to identify the relevant articles till September 2020 following Cochrane and PRISMA guidelines. We extracted data including the number of patients, source of hematopoietic stem cells, their mobilization and conditioning regimens, results, and complications from the eligible studies.



peer reviewed.

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Grade D (Fair): 0  
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Results were dichotomized into success (ACR 50/70) and failure (ACR 20) based on the improvement from baseline characteristics. The methodological quality of the included studies was also assessed. Analysis was performed using OpenMeta[Analysis] software.

## RESULTS

We included 17 studies (1 randomized controlled trial, 11 prospective, and 5 retrospective studies) with 233 patients for analysis. HSCT provided a significantly beneficial overall improvement in the clinical grades of ACR criteria ( $Z = 11.309$ ,  $P < 0.001$ ). However, the remission was noted only till 24 mo and later on the significance of the result was lost ( $Z = 1.737$ ,  $P = 0.082$ ). A less than 1% treatment-related mortality was noted from the included studies. No major drug-related toxicities were noted in any of the included studies. All patients who underwent allogeneic HSCT received immunosuppression in the conditioning regimen to counteract the graft-*vs*-host reaction which made them vulnerable to infections. It is noted that the source of hematopoietic stem cells did not play a role in altering the functional outcome and both autologous ( $Z = 9.972$ ,  $P < 0.001$ ) and allogenic ( $Z = 6.978$ ,  $P < 0.001$ ) sources produced significant improvement in the outcome compared to the pre-operative state despite having a significant heterogeneity among the studies reporting them ( $I^2 = 99.4$ ,  $P < 0.001$ ).

## CONCLUSION

Although the available literature is encouraging towards the use of HSCT in refractory cases with significant improvement from baseline till 2 years, the inclusion of HSCT into the standard of care of RA needs further exploration.

**Key Words:** Hematopoietic stem cell; Rheumatoid arthritis; Disease-modifying anti-rheumatic drug; Biological therapy; Systematic review; Meta-analysis

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**Core Tip:** With the rising resistance to the traditional disease-modifying anti-rheumatic drugs and targeted biological therapy, we performed this systematic review and meta-analysis to evaluate the role of hematopoietic stem cell therapy in the management of rheumatoid arthritis. Literature on the effectiveness of the intervention is encouraging with significant improvement till 2 years post-therapy. We have explored the ambiguity in the current treatment methods in hematopoietic stem cell therapy that needs further exploration to optimize the results out of this treatment modality.

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## INTRODUCTION

Rheumatoid arthritis (RA) is an autoimmune disorder essentially triggered by the activation of fibroblast like synovocytes which in turn triggers a series of inflammatory reactions leading to the disease process[1,2]. The treatment of this disease has been closely evolving with an understanding of its pathogenesis. The key principle guidelines recommended in their routine management include: Disease-modifying anti-rheumatic drugs (DMARDs) is started as soon as possible after diagnosis, methotrexate remains the best drug of choice to start with, serial monitoring of disease activity is adopted, use of biologics is limited to patients with persistently active disease refractory to methotrexate, and the treatment target aims for remission or low disease activity[3]. Hematopoietic stem cell (HSC) transplantation (HSCT) is a misnomer because the procedure involves the infusion of the patient's stem cells. HSCT is being accepted as a standard of care in various inflammatory diseases such as

multiple sclerosis, systemic sclerosis, aplastic anaemia, and various immune-mediated cytopenias[4-6]. It is now being widely used for rheumatological diseases such as systemic lupus erythematosus and vasculitic conditions[7,8].

HSCT as a treatment option in the management of RA has been tried with contrasting results[9-13]. With the introduction of biologic therapy for RA, HSCT was resorted only to refractory cases not responding to DMARD[14]. Since the ultimate goal of the ideal treatment of RA is to restore immune tolerance, HSCT attracts much attention considering its reparative, paracrine, and anti-inflammatory effects. However, information on the implications of this therapy including their clinical response rate and complications is limited from the sources like European Group for Bone Marrow Transplantation (EMBT) data registry and Autologous Blood and Marrow Transplant Registry[15].

While many reviews are available evaluating the role of HSCT in various inflammatory disorders[6-8,16], this is the first systematic review article to analyze the effectiveness of HSCT in RA. In this review, we intend to summarize the available evidence on the role of HSCT in the management of RA and analyze whether it holds a future in the treatment spectrum, and discuss some of the potential queries that need further exploration for the applicability in the current scenario of disease management.

## MATERIALS AND METHODS

We followed Cochrane guidelines and Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) guidelines[17,18] for the conduction and reporting of this systematic review. We included studies that satisfied the below mentioned PICOTS criteria: (1) Population: Patients with RA; (2) Intervention: HSCT; (3) Comparator: Placebo; (4) Outcome: American College of Rheumatology (ACR) 20/50/70 criteria of improvement from baseline; (5) Timeline: Minimum 6 mo follow-up period; and (6) Study design: Any study design satisfying PICOT.

### Search strategy

In September 2020, two reviewers (SM and MJ) performed an extensive independent search of electronic databases - PubMed, Scopus, Embase, Cochrane, and the Web of Science - to identify all the relevant studies using keywords: "Rheumatoid arthritis", "RA", "Inflammatory Arthritis", "Stem Cell", and "Hematopoietic Stem Cell". The search strategy used for PubMed has been provided in [Supplementary File 1](#). The reference list of the selected articles was also searched to identify studies not identified in the primary search. As per the inclusion and exclusion criteria, eligible studies were included in the systematic review. We utilised kappa statistics to analyse the level of agreement of the reviewers for the inclusion of studies in the review and any discrepancy between the authors was resolved through discussion until a consensus was obtained.

### Data extraction

Two reviewers (SM and MJ) retrieved independently relevant data from articles included for analysis. The following data were extracted: (1) Study characteristics: Year of publication, authors, nature of the study, and number of patients involved; (2) Baseline characteristics: Age, source of HSC (autologous/allogenic), HSC mobilization regimen, HSC manipulation methods utilized, HSC characterization, HSC conditioning regimen, and follow-up period; (3) Main outcome: ACR 20/50/70 criteria of improvement from baseline; and (4) Secondary outcome: Complications.

We expected heterogeneity in the scales and scores utilized for reporting the functional outcome of HSCT in the included studies. Hence, we utilized the standard ACR 20/50/70 criteria to categorize the outcome of the patients undergoing HSCT for RA which was commonly used in the studies[19]. In case of studies not reporting their outcome based on the ACR criteria, we utilized the description of recovery of the patient to categorize them under the ACR 20/50/70 criteria and if sufficient information was not available from the study, the corresponding authors were contacted for further information to categorize the patient into appropriate categories.

For ease of analysis, we dichotomized the results of HSCT into treatment success if the patients achieved a minimum of ACR50 criteria of improvement from the baseline as used by Nikolov *et al*[20]. Moreover, we also expected the included studies to have a variable follow-up period. Hence, we grouped the studies based on their follow-up period to analyze the results of the studies on HSCT for RA at various time points following the procedure. We utilised kappa statistics to analyse the level of agreement

of the reviewers in data extraction and any disagreements were resolved by discussion until a consensus was achieved.

### **Risk of bias and quality assessment**

The methodological quality of the included studies was assessed independently by two reviewers using the risk of bias tool for case series and case reports given by Murad *et al*[21]. Risk of bias of the randomized controlled trials was estimated using the RoB 2 tool of Cochrane Collaboration[22]. To evaluate the methodological index of the prospective non-randomized studies, we utilized MINORS criteria[23].

### **Statistical analysis**

Meta-analysis of the pooled data was performed in the R platform using the OpenMeta[Analyst] software[24]. For dichotomous variables, we utilized proportions with 95% confidence intervals (CIs). We evaluated the heterogeneity of the pooled data using  $I^2$  statistics. If  $I^2 < 50\%$  and  $P > 0.1$ , a fixed-effects model was employed in meta-analysis and if  $I^2 > 50\%$  and  $P < 0.1$ , a random-effects model was utilised. A  $P$  value  $< 0.01$  was considered significant. We performed sensitivity analysis and subgroup analysis to explore the source of heterogeneity when it existed.

## **RESULTS**

### **Search results**

The electronic database search resulted in 919 articles which after initial screening for duplicate removal gave a total of 714 articles. Title and abstract screening were done in those articles and 195 of them were excluded. Nineteen articles were qualified for full-text review. We noted that none of the studies utilized a dual-arm study design to compare the effectiveness of the therapy against control as intended. Instead, we found 17 single-arm studies which analyzed the results of HSCT for RA. Hence, we included those 17 studies into the systematic review and performed a single-arm meta-analysis of the reported results stratified based on their study design. PRISMA flow diagram of the study selection is given in Figure 1. The list of studies excluded from full-text screening with the reason for their exclusion is provided in Supplementary File 2. The inter-reviewer kappa agreement was strong in both study selection and data extraction process with kappa values 0.84 and 0.89, respectively.

### **Quality assessment**

The methodological quality of the included studies was given in Table 1. The included studies did not show a high risk of bias to warrant exclusion. The included case reports satisfied all the criteria laid down by Murad *et al*[21] to be eligible for consideration in systematic review and analysis. The range of MINORS score achieved by the prospective studies was from 12-15, which is acceptable for analysis. The randomised controlled trial (RCT) by Moore *et al*[13] showed a low risk of bias among all five domains of assessment for inclusion into the analysis based on the RoB2 tool of Cochrane Collaboration.

### **General characteristics**

Seventeen studies including one RCT[13], eleven prospective studies[9,11,15,25-32], and five retrospective studies[12,33-36] involving 233 patients were qualified for this systematic review. The baseline characteristics of the included studies are shown in Table 2. Although the publication timeline showed a steady increase in the total number of publications since 1997 to 2005, it was followed by an abrupt cessation of studies owing to the introduction of biological therapy in the management spectrum of RA. However, the common indication for HSCT in RA in the included studies was patients who failed to respond to the traditional lines of management with classical DMARDs or biological therapy. The age of the population included for analysis ranged from 18–65 years. Of the 17 included studies, 14 utilized autologous HSCT, and 3 utilized allogeneic HSCT from compatible donors.

### **Mobilization regimen**

Of the 14 studies that utilized autologous HSCT for RA, all utilized granulocyte colony stimulating factor (G-CSF) for progenitor cell mobilization at a dosage ranging from 5–10  $\mu\text{g/kg}$  and cyclophosphamide (CYC) at a variable non-myeloablative dosage ranging from 1.5  $\text{g/m}^2$  to 4  $\text{g/m}^2$ . Etoposide was also used along with CYC by Durez *et*

**Table 1 Methodological quality and risk of bias assessment of the included studies (n = 17)**

Randomized controlled trial								
Ref.	Randomization process	Deviation from the intended interventions	Missing outcome data	Measurement of the outcome	Selection of the reported result	Overall Bias		
Moore <i>et al</i> [13]	Low risk	Low risk	Low risk	Low risk	Low risk	Low risk		
Prospective studies								
Ref.	A clearly stated aim	Inclusion of consecutive patients	Prospective collection of data	Endpoints appropriate to the aim of the study	Unbiased assessment of the study endpoint	Follow-up period appropriate to the aim of the study	Loss to follow up less than 5%	Prospective calculation of the study size
Tyndall <i>et al</i> [29]	1	1	2	2	2	1	2	1
Burt <i>et al</i> [26]	2	2	2	1	2	1	2	1
Burt <i>et al</i> [25]	2	2	2	1	2	1	2	1
Verburg <i>et al</i> [30]	2	2	2	2	2	2	2	1
Snowden <i>et al</i> [27]	2	2	2	1	2	1	2	1
van Laar <i>et al</i> [28]	2	2	2	2	2	2	2	1
Snowden <i>et al</i> [15]	1	1	2	1	2	1	2	1
Bingham <i>et al</i> [11]	2	2	2	2	2	2	2	1
Teng <i>et al</i> [9]	2	2	2	2	2	2	2	1
Pavletic <i>et al</i> [31]	2	2	2	2	2	2	2	1
Verburg <i>et al</i> [32]	2	2	2	2	2	2	2	1
Case reports								
Ref.	Selection score	Ascertainment score	Causality score	Reporting score	Total score			
Silva <i>et al</i> [12]	1	2	1	1	5			
Joske <i>et al</i> [33]	1	1	1	1	4			
Kim <i>et al</i> [35]	1	2	1	1	5			
Durez <i>et al</i> [34]	1	1	1	1	4			
Burt <i>et al</i> [36]	1	2	1	1	5			

*al*[34] Similarly, all the studies utilized leukapheresis to remove the autoimmune inflammatory cells from the circulation. All the included studies manipulated the cells mobilized by selective isolation of CD 34+ cells. Two of them compared the effect of this selective manipulation in their study and did not find any substantial benefit out of the process[10,15]. The complete HSCT protocol including the mobilization protocol followed by the individual studies is given in Table 3.

**Table 2** General characteristics of the included studies (*n* = 17)

Sl. No	Ref.	Year	Study design	Indication	Sample size	Age (yr)	Source (Autologous/allogenic)	Mean follow-up (mo)
1	Joske <i>et al</i> [33]	1997	Case report	Failed DMARDs	1	46	Autologous	6
2	Durez <i>et al</i> [34]	1998	Case report	Failed DMARDs	1	22	Autologous	10
3	Burt <i>et al</i> [26]	1998	Prospective study	Failed DMARDs	2	44	Autologous	12
4	Snowden <i>et al</i> [27]	1999	Prospective study	Failed DMARDs	8	18-65	Autologous	18
5	Burt <i>et al</i> [25]	1999	Prospective study	Failed DMARDs	4	46.2	Autologous	12
6	Kim <i>et al</i> [35]	2002	Case report	Failed DMARDs	1	54	Autologous	6
7	Tyndall <i>et al</i> [29]	2001	Prospective study	Primary treatment	43	NR	Autologous	11
8	van Laar <i>et al</i> [28]	2001	Prospective study	Failed DMARDs	8	18-60	Autologous	18
9	Verburg <i>et al</i> [30]	2001	Prospective study	Failed DMARDs	14	43	Autologous	12
10	Bingham <i>et al</i> [11]	2001	Prospective study	Failed DMARDs	6	37.33	Autologous	20
11	Pavletic <i>et al</i> [31]	2001	Prospective study	Failed DMARDs	6	42.5	Autologous	26.5
12	Moore <i>et al</i> [13]	2001	RCT	Failed DMARDs	33	18-65	Autologous	12
13	Burt <i>et al</i> [36]	2004	Case report	Failed DMARDs	1	52	Allogenic	12
14	Snowden <i>et al</i> [15]	2004	Prospective study	Failed DMARDs	73	42	Autologous	18
15	Verburg <i>et al</i> [32]	2005	Prospective study	Failed DMARDs	8	35-55 years	Autologous	24
16	Teng <i>et al</i> [9]	2005	Prospective study	Failed DMARDs	8	43	Allogenic	60
17	Silva <i>et al</i> [12]	2018	Retrospective study	Failed DMARDs (10), failed autologous HSCT (1), secondary haemophagocytic lymphohistiocytosis (5)	16	12	Allogenic	29

DMARDs: Disease modifying anti-rheumatic drugs; HSCT: Haematopoietic stem cell transplant; NR: Not reported; RCT: Randomised controlled trial.

### Conditioning regimen

The commonly employed drug in the conditioning regimen of the included studies to avoid rejection of HSCT in the RA patients was CYC at a dosage ranging from 100-200 mg/kg. In addition to CYC, anti-thymocyte globulin (ATG) was used in 5/17 included studies at a constant dose of 90 mg/kg [25,26,29,35], and busulfan in one of them at 4 mg/d dosage [34]. Two studies utilized fludarabine and alemtuzumab in their conditioning regimen. The detailed list of drugs used by the individual studies in their conditioning regimen is given in Table 3.

### Functional outcome

We noted significant heterogeneity among the scales used for the assessment of the functional improvement in the included studies such as ACR outcome improvement criteria, Visual Analog Scale, Health Assessment Questionnaire, Disease Activity Score, Larsen Score, C-reactive protein level, Erythrocyte Sedimentation Rate, and Rheumatoid Factor. However, ACR was the most commonly employed outcome measure in HSCT to assess the functional outcome post-procedure. Hence, we



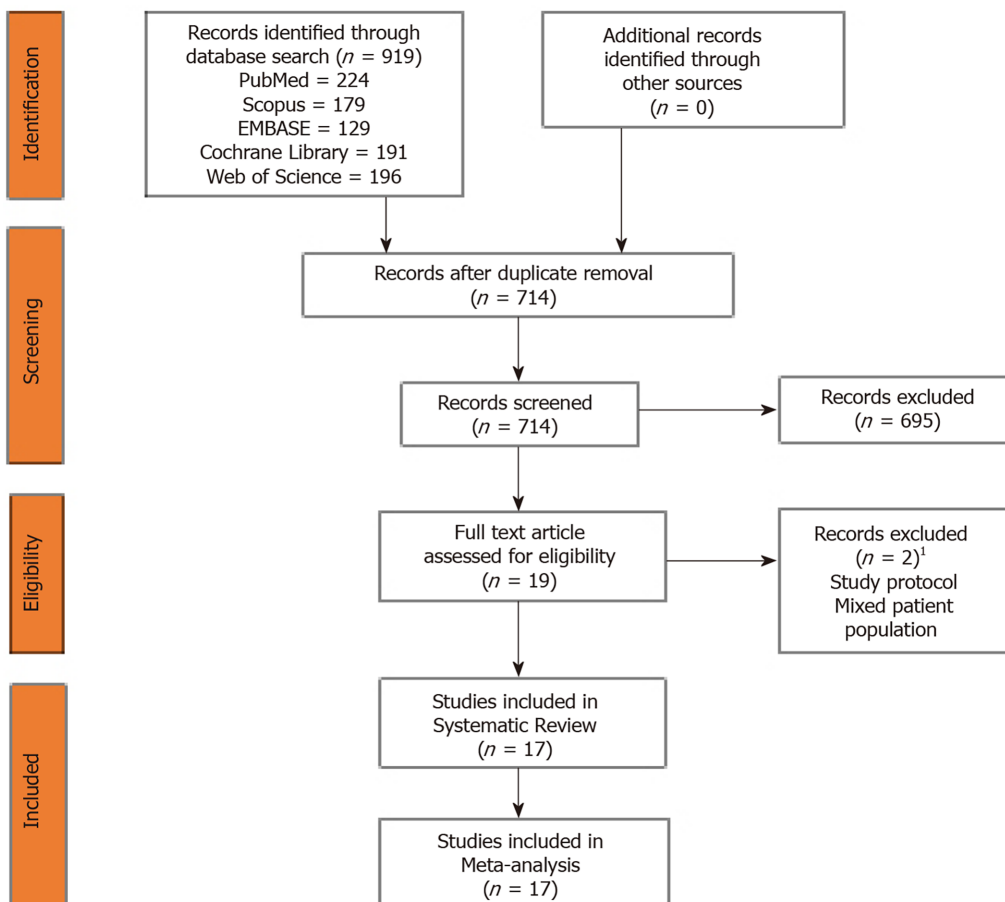
**Table 3 Hematopoietic stem cell transplant protocol in the included studies (n = 17)**

Sl. No	Ref.	Mobilization regimen	Graft manipulation	HSC selection	Conditioning regimen
1	Joske <i>et al</i> [33]	CYC 4 g/m <sup>2</sup> , G-CSF 10 µg/kg	Leukapheresis	CD 34 +ve selection	CYC 200mg/kg
2	Durez <i>et al</i> [34]	CYC 1.5 g/m <sup>2</sup> , etoposide 300 mg/m <sup>2</sup> , G-CSF 5 µg/kg	Leukapheresis	CD 34 +ve selection	CYC 60 mg daily and busulfan 4 mg daily
3	Burt <i>et al</i> [26]	CYC, G-CSF	Leukapheresis	CD 34 +ve selection	CYC 200 mg/kg, ATG 90 mg/kg
4	Snowden <i>et al</i> [27]	CYC 100-200 mg/kg, G-CSF 5 µg/kg	Leukapheresis	CD34 +ve selection	CYC 100 mg/kg or 200 mg/kg
5	Burt <i>et al</i> [25]	CYC 2 g/m <sup>2</sup> , G-CSF	Leukapheresis	CD34 +ve selection	CYC 200 mg/kg, ATG 90 mg/kg
6	Kim <i>et al</i> [35]	CYC 4 g/m <sup>2</sup> , G-CSF 5 µg/kg	Leukapheresis	CD 34 +ve selection	CYC 200 mg/kg, ATG 90 mg/kg
7	Tyndall <i>et al</i> [29]	CYC, G-CSF	Leukapheresis	NR	CYC 200 mg/kg, ± ATG 90 mg/kg, ± Busulfan
8	van Laar <i>et al</i> [28]	CYC 4 g/m <sup>2</sup> , G-CSF 10 µg/kg	Leukapheresis	CD34 +ve selection	CYC 200 mg/kg
9	Verburg <i>et al</i> [30]	CYC 4 g/m <sup>2</sup> , G-CSF 10 µg/kg	Leukapheresis	CD 34 +ve selection	CYC 200 mg/kg
10	Bingham <i>et al</i> [11]	CYC 2 g/m <sup>2</sup> , G-CSF	Leukapheresis	CD 34 +ve selection	CYC 200 mg/kg
11	Pavletic <i>et al</i> [31]	CYC 2 g/m <sup>2</sup> , G-CSF	Leukapheresis	CD34 +ve selection	CYC 200 mg/kg, ATG 90 mg/kg
12	Moore <i>et al</i> [13]	CYC 200 mg/kg, G-CSF 10 µg/kg	Leukapheresis	CD34 +ve selection (18) / No selection (15)	CYC 200 mg/kg
13	Burt <i>et al</i> [36]	NA	NA	CD 34 +ve selection	CYC 150 mg/kg, fludarabine 125 mg/m <sup>2</sup> , alemtuzumab 20 mg
14	Snowden <i>et al</i> [15]	CYC 200 mg/kg, G-CSF 5-10 µg/kg	Leukapheresis	CD 34 +ve selection (45) / No selection (28)	CYC 200 mg/kg
15	Verburg <i>et al</i> [32]	CYC 200 mg/kg, G-CSF	Leukapheresis	CD 34 +ve selection	CYC 200 mg/kg
16	Teng <i>et al</i> [9]	NA	NA	CD 34 +ve selection	CYC 200 mg/kg
17	Silva <i>et al</i> [12]	NA	NA	CD 34 +ve selection	Fludarabine 30 mg/m <sup>2</sup> /d, melphalan 140 mg/m <sup>2</sup> /d, alemtuzumab 0.2 mg/kg/d or fludarabine 30 mg/m <sup>2</sup> /d, treosulfan 14 mg/m <sup>2</sup> /d, alemtuzumab 0.2 mg/kg/d

ATG: Anti-thymocyte globulin; CD: Cluster differentiation; CYC: Cyclophosphamide; G-CSF: Granulocyte colony stimulating factor; HSC: Hematopoietic stem cell; NA: Not applicable; NR: Not reported.

converted the outcome of all the studies included under ACR criteria based on the outcome characteristics reported. Significant heterogeneity existed in the ACR results among the included studies ( $I^2 = 81.86\%$ ,  $P < 0.001$ ). Hence, a random-effects model was utilized for analysis.

We also found the follow-up period of the included studies to range from 6-60 mo. Hence, we grouped the studies based on their follow-up period to analyze the results at various time points following the procedure. Figure 2 shows the change in the grades of ACR criteria at various time points among the included studies using HSCT for RA. Figure 3A shows the forest plot of analysis of results of studies at various time points following HSCT in comparison to their pre-operative status of RA using a random binary effects model. HSCT provided a significantly beneficial overall improvement in the clinical grades of ACR criteria ( $Z = 11.309$ ,  $P < 0.001$ ). A significant difference in the preoperative state of ACR was noted till 24 mo and later on the significance of the result was lost ( $Z = 1.737$ ,  $P = 0.082$ ) as shown in Figure 3A.



**Figure 1 Preferred reporting items for systematic reviews and meta-analyses flow diagram of the included studies.** <sup>1</sup>List of excluded studies given in Supplementary File 2.

We explored the heterogeneity among the included studies through subgroup analysis of the results based on the nature of HSCT (*i.e.*, autologous and allogeneic types) and presented the results in **Figure 3B**. It was noted that the source of HSCT did not play a role in altering the functional outcome and both autologous ( $Z = 9.972$ ,  $P < 0.001$ ) and allogeneic ( $Z = 6.978$ ,  $P < 0.001$ ) sources produced significant improvement in the outcome compared to the pre-operative state despite having a significant heterogeneity among the studies reporting them ( $I^2 = 99.4$ ,  $P < 0.001$ ). On exploring the heterogeneity, variability was noted in the follow-up period of the included studies despite maintaining the significance of the outcome results.

### Complications

Despite using a non-myeloablative regimen in the HSCT protocol, the patients tended to undergo a spectrum of side effects. The routine side effects of chemotherapy such as nausea, vomiting, hair loss, skin rash, and fever were noted in most of the patients. We took into account the procedure-related mortality, drug-related major toxicities, and grade III/IV graft-*vs*-host reaction (GVHD) as significant complications due to the procedure and analyzed their prevalence among the included studies. One transplant-related death was noted by Tyndall *et al*[29] and death due to sepsis was noted in a study by Snowden *et al*[15]. We noted a  $< 1\%$  (2/233) procedure-related mortality from the included studies. No major drug-related toxicities were noted in any of the included studies.

All patients who underwent allogeneic HSCT received immunosuppression in the conditioning regimen to counteract the GVHD which made them vulnerable to infections. High-grade GVHD was noted in patients undergoing allogeneic HSCT by Silva *et al*[12] along with a higher prevalence of viral infections noted in them. It was noted from the forest plot that HSCT was not associated with a significant increase in the listed major complications ( $P = 0.015$ , 95% CI: 0.005-0.041) as shown in **Figure 3C**. However, it should be prudent to consider on a case-by-case basis whether these risks outweigh the benefits from the therapy.

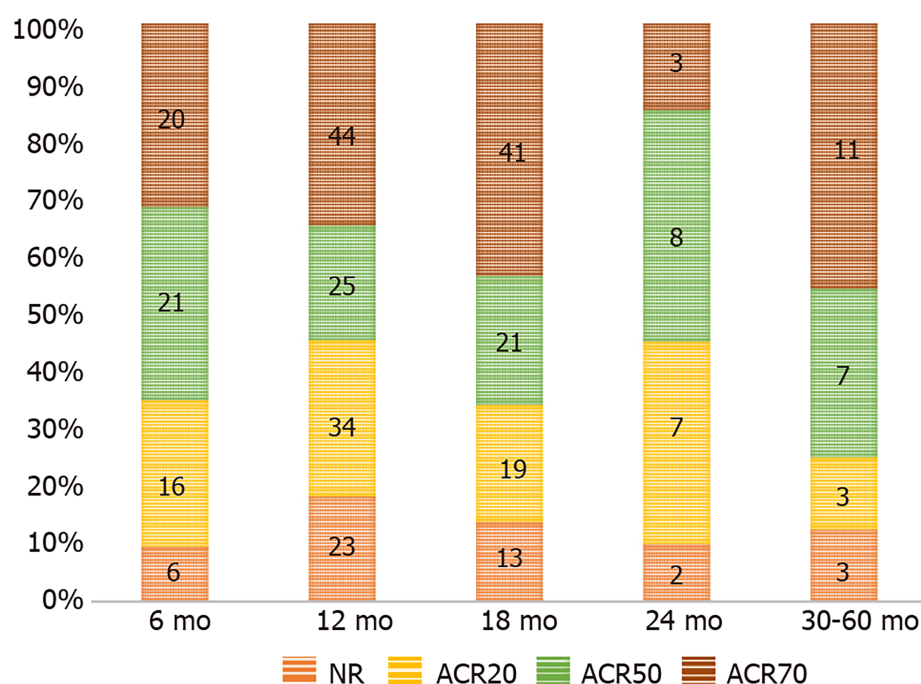


Figure 2 Transition trend of American College of Rheumatology criteria in the included studies across various time points.

### Sensitivity analysis

A sensitivity analysis was performed in each analysis. The results of the outcomes analysed were not significantly altered by sequentially omitting each study in the meta-analysis within each study design. On the other hand, the consistency of the results was maintained after reanalysis by changing the random-effects model.

## DISCUSSION

Despite the usage of both conventional DMARDs and newer biologicals, 40% of patients with RA continue to have frequent relapses with active and progressive disease[20,37]. Autologous HSCT has been considered as an alternative modality of management of such resistant candidates[38]. Although HSCs are multipotent stem cells with the potential to give rise to blood, endothelial cells, and immune cells, in the context of their role in autoimmune diseases they are viewed as immune stem cells [39]. The major complication from the HSCT arises not from the HSC transfer itself but from the immunosuppressive conditioning regimens utilized to inhibit the autoreactive immune cells before the transfer[8]. The rationale of using the immunosuppressive conditioning regimens is not to myeloablate the host immune system but to lymphoablate the autoimmune cells so that immune regeneration starts from the transferred HSCs[20]. These non-myeloablative regimens used in the included studies commonly employed CYC as shown in Table 2. Special attention should be given to the regimen-related side effects particularly from the high dose CYC which forms the backbone of these regimens[40].

Response to the HSCT was shown by the reduction in the serum auto-antibody titers noted in the included studies[10-12]. This shows a temporal relationship between the immune balance restoration and clinical response outcomes as a precondition to get immune tolerance in RA patients[41]. However, to obtain optimal results from the HSCT patient selection is of key importance. Although HSCT is recommended for patients who failed conventional spectrum of management, good results from HSCT are obtained from patients presenting with an early aggressive disease with poor prognostic factors who also have enough residual functional capacity to benefit out of the procedure[14,42].

HSCT is also associated with considerable morbidity and treatment-related mortality (TRM). Based on the registry data, 1-year transplant-related mortality due to autologous HSCT for haematological malignancies was 2%-5%[43]. However, from the included studies we noted a < 1% TRM from the HSCT procedure for RA. The most

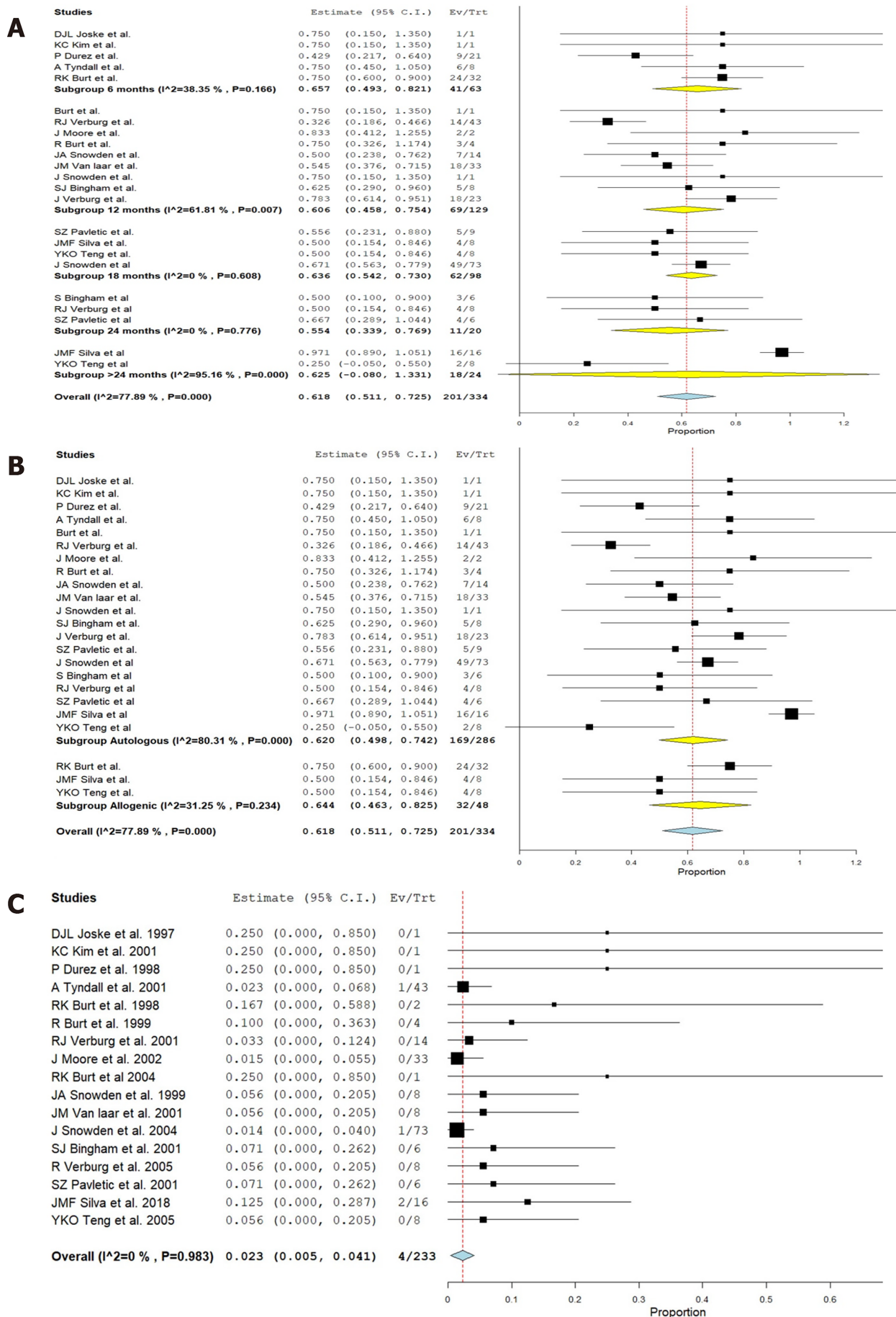


Figure 3 Forest plot. A: Analysis of results of included studies at various time points following hematopoietic stem cell transplantation (HSCT) in comparison to



their pre-operative status of rheumatoid arthritis using a random binary effects model; B: Sub-group analysis of the results based on the nature of HSCT (autologous and allogeneic types); C: Major complications noted in the included studies.

common complication encountered with HSCT from all the included studies is infection due to the immunosuppression that accompanies the conditioning protocol followed[44]. Owing to the neutropenia, bacterial or fungal infections may occur and lymphopenia may lead to latent viral and opportunistic infections[45]. This has been counteracted by the empirical use of broad-spectrum antibacterial, antiviral, and antifungal medication in this high-risk period post-transplantation.

The risk of TRM and toxicity depends not only on the HSCT protocol used but also on the source of the donor cells[46]. Allogeneic HSCT is associated with a higher risk of complications especially due to the GVHD associated with them. Most of the adverse events are associated with the conditioning regimens utilized following allogeneic HSCT[45]. To clear the autoreactive inflammatory cells causing GVHD an array of conditioning regimens including drugs such as fludarabine, melphalan, alemtuzumab, and treosulfan along with CYC have been utilized in the included studies[9,12]. To optimize the safety of the procedure, the treatment must be offered after preliminary screening for comorbidities and cardiopulmonary ailments and administration of the regimens in dedicated centres with appropriate supportive care to make the procedure successful and safe.

### **Cost-effectiveness**

With due consideration to the selected group of patients who is eligible for HSCT, the impact of the disease on society is far from negligible[47]. Although they are small in proportion, consumption of the health care services by these seriously ill patients remains significant[48]. Compared to the lifetime costs incurred in the management of such resistant cases of RA utilizing biologically targeted therapies which are required in the long term without any guaranteed universal effectiveness[49], HSCT appears a promising cost-effective strategy although it is also an expensive treatment by itself. A complete remission out of HSCT would lead to significant cost savings in the long run [50,51]. Apart from the economic benefits, complications of chronic immunosuppressive therapies with targeted biologicals could be avoided with the use of HSCT [50]. So far, no cost-effectiveness analysis has been made for HSCT in RA.

### **Future recommendations**

Before the inclusion of HSCT into the routine management protocol for RA, certain questions need further exploration to standardize the treatment protocol to harness maximum benefits out of the procedure. The potential questions that need answering in the various stages of HSCT are enumerated in [Figure 4](#).

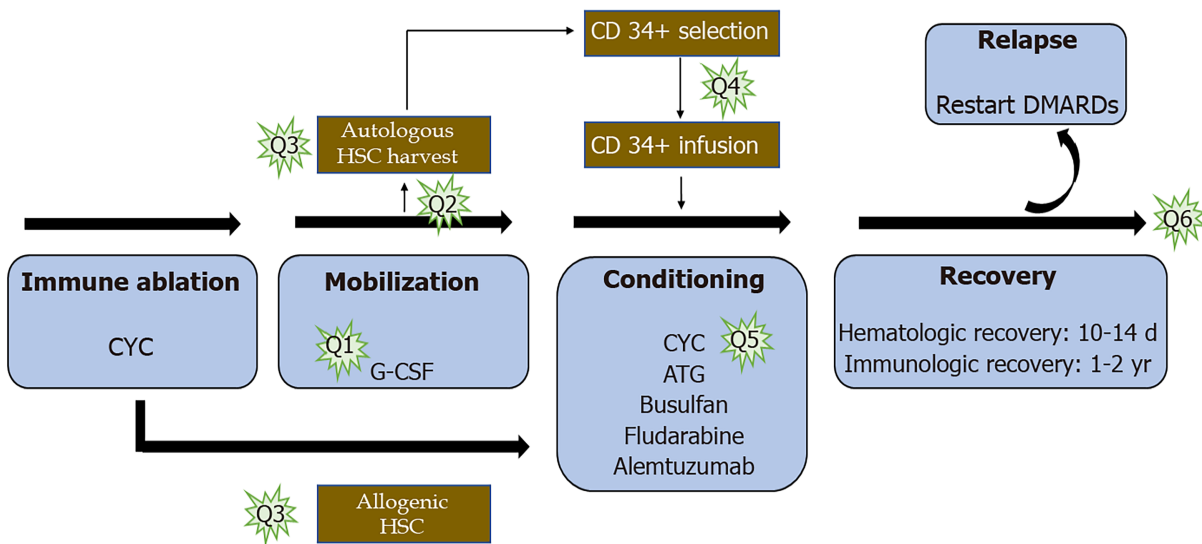
#### **Question 1: Is stem cell rescue necessary after high dose immune ablation?**

With the studies reporting complete remission of severe cases of RA after a myeloablative dose of CYC without being followed by HSCT[52], a question arises as to whether the procedure needs firsthand. Regeneration of the marrow function similar to HSCT was noted but at a slower pace. Introducing the auto-immune lymphocytes into the host following a high dose of CYC may be a reason for noted failure in some of the cases of autologous HSCT[52]. Although the concept appears appealing, whether it could be qualified to be investigated under a clinical trial poses ethical considerations. However, one could plan for a trial with and without immediate stem cell rescue following high dose CYC therapy for RA patients[53].

#### **Question 2: What is the ideal source of HSCs?**

There has been a shift in the source of autologous HSCT from bone marrow (BM) to peripheral blood stem cells (PBSC) because of the rapid haematological recovery especially platelet and neutrophil counts following reinfusion when PBSC are used as a source of HSCT[54]. It also makes the procedure more cost-effective[55]. But it is also noted that, when PBSC is used as a source of HSCT, an 11-fold increase in T cells and an 8-fold increase in B-cells were noted, thereby making them less likely to provide any sustained benefit compared to the BM source which has a less cellular load on reinfusion[56]. It is also not evident whether the peripheral T cell counts have any temporal association with the damage caused by the disease. One other finding in allogeneic HSCT is that patients who undergone HSCT with PBSC source did not document any proportional increase in GVHD compared to BM source[57]. Hence,





**Figure 4 Potential areas of future research to optimize hematopoietic stem cell transplantation treatment for rheumatoid arthritis.** Q1 is to evaluate whether stem cell rescue is necessary after high dose immune ablation; Q2 is to assess the ideal source of hematopoietic stem cells (HSCs); Q3 deals with either autologous or allogeneic source; Q4 deals with the need for T cell depletion from the harvested material; Q5 probes into the ideal conditioning regimen; and Q6 evaluates the ideal timing of HSC transplantation in the course of the disease. HSC: Hematopoietic stem cell.

comparative long-term clinical trials to explore the ideal source of HSCs are needed to further explore this issue.

### Question 3: Autologous or allogeneic HSCT?

There is a theoretical concern in allogeneic HSCT that the patient's immune cells could not be able to continue the disease process following intensive immunosuppressive therapy since the reconstituted immune progenitors belong to the donor. Moreover, the donor T cell elicits a GVHD which enables elimination or suppression of the residual autoimmune clones in the body. We do not have any evidence on this “graft-versus-autoimmune disease” effect, to state a correlation between the degree of GVHD and the resolution of the disease process to weigh one over the other.

### Question 4: Should T cells be depleted from the harvested material?

Although phase I and phase II clinical studies have established the therapeutic potential, clinical safety, and efficacy of HSCT therapy[20], there is a paucity of literature to provide a consensus on whether the lymphocytes from the collected peripheral HSCs should be depleted before re-infusion. Although T-cell depletion (TCD) prevents the re-entry of autoimmune cells in the system, the procedure bears the risk of late opportunistic infections especially those by cytomegalovirus and Epstein-Barr virus[44]. There is a current understanding that complete lymphoablation may not be needed since the immune reset happens with the development of the immune regulatory networks and immune tolerance. Moreover, Joske *et al*[33] in their study did not find any significant difference due to CD34+ selection either. Hence, the need for TCD has to be further explored with randomized controlled trials to arrive at a definite conclusion on this aspect of HSCT.

### Question 5: What is an ideal conditioning regimen?

Most of the included studies utilized CYC based regimens to minimize the effect of residual autoreactive clones in the body. The effect of the conditioning regimen used on the results of the transplant remains unexplored although the intensity of the conditioning might play a role. Most of the included studies utilized CYC at a high dose of 200 mg/kg administered for 4 d. Such high dose chemotherapy has its side effects such as hemorrhagic cystitis. Further research to identify alternative conditioning regimens that are immunosuppressive without being myelosuppressive and also prolong the remission achieved in patients is needed. Other combinations such as regimens containing ATG were also tried in some of the included studies as shown in Table 2. Administration of G-CSF in the post-transplant state would shorten the recovery period but in some cases, G-CSF has been shown to trigger an exacerbation of arthritis which needs further exploration[58]. Moreover, clinical trials are needed to

evaluate the difference between regimens with enhanced immunoablative capacity where the greater toxicity is justified with prolonged remission and conventional regimens with added post-transplant immune suppression to prolong the remission.

### **Question 6: What is the ideal timing of HSCT?**

The major challenge in utilizing HSCT for RA is the timing of initiation of the treatment in the course of the disease. If the patient is considered for HSCT after a trial of response to immunosuppressive therapy with DMARDs, the disease could have evolved beyond the point of maximum benefit from HSCT since they are less effective in patients with advanced organ damage and immune dysregulation. Since there are no specific guidelines to the timing and patient profile selection for enrolling into HSCT, the decision largely lies in the hands of the patients and their treating physicians. Clinicians should help the patients choose the right treatment by weighing their pros and cons together and provide clear information to aid in the decision-making process considering the prognostic factors associated with the disease process in the individual patients[59]. Although the treatment seems promising, the guidelines drafted by the European League against Rheumatism (EULAR) and EMBT for patient selection for optimal response need further improvement on the above-mentioned areas.

The small sample size of the included studies with heterogeneity in their patient selection methods, HSCT protocols utilized, the reported results, and their definition of remission limits their utility in decision making. In the absence of large clinical trials, a Markov clinical decision analysis to compare the conventional therapy with HSCT could be utilized. The model predicted HSCT to be superior to conventional therapy if the TRM could be maintained < 3.3% or if the treatment results are sustainable for 5 years. Having done in the early era of biological therapy, these analyses emphasize that a subset of RA patients could also benefit from HSCT. The differences in the Quality Adjusted Life Years between the two groups involved in the model reinstate the role of the patients in the decision-making process[9]. With the improvement in the treatment methods, the safety of the procedure has largely been improved. In selected cases, HSCT may remain the only effective method available making these risks acceptable. Yet, the decision lies in the hands of the patient, hence it needs careful discussion before making the treatment choice. With the rise in the resistance to traditional therapy for RA, earlier identification of those non-responders based on clinic-serological profile and prognostic markers remains a key element to reap the maximum benefit out of this modality.

## **CONCLUSION**

Although the available literature is encouraging towards the use of HSCT in refractory cases with significant improvement from baseline till 2 years, the inclusion of HSCT therapy into the standard of care of RA needs further exploration. With the rising proportion of non-responders to conventional DMARDs and biologic therapy, HSCT therapy would find a place in the treatment spectrum of RA provided that large clinical trials with longer follow-up are conducted to establish the ideal treatment strategy to get optimal results out of this treatment modality.

## **ARTICLE HIGHLIGHTS**

### **Research background**

Hematopoietic stem cell (HSC) transplantation (HSCT) has been accepted as a treatment method in the management of various inflammatory diseases. With the evolution in the management of rheumatoid arthritis (RA), and the rising resistance to the traditional disease-modifying anti-rheumatic drugs, researchers are in pursuit of alternate methods for disease management. Having the ultimate goal of achieving systemic immune tolerance, HSCT has now been considered in the management of RA with respect to its reparative, paracrine, and anti-inflammatory properties.

### **Research motivation**

Despite the understanding of the potential of HSCT towards immune reconstitution, considering RA to be an auto-immune disease, a systematic review of studies on utilization of HSCs in RA is lacking. If HSCT proves to be useful in refractory cases of

RA, future studies to strengthen the evidence on the same could be recommended.

### Research objectives

To investigate the role of HSCT in the management of RA.

### Research methods

A detailed search of PubMed, Scopus, EMBASE, Cochrane, and the Web of Science databases was made to identify the relevant articles till September 2020 following Cochrane and PRISMA guidelines. All the studies included were analyzed to evaluate the role of HSCT in RA by dichotomizing their outcome based on American College of Rheumatology (ACR) criteria for success (ACR 50/70) and failure (ACR 20) based on the improvement from baseline characteristics. The methodological quality of the included studies was also assessed. Analysis was performed using OpenMeta [Analysis] software.

### Research results

Upon meta-analysis of the 17 included studies on the use of HSCT for refractory cases of RA, it was noted that remission was maintained for 2 years. However, for the implementation of the intervention into routine clinical practice, further studies are needed to shed some light on the ideal source of the HSCs for transplantation, the ideal conditioning regimen to be utilized, and the ideal timing of transplantation to reap the maximum benefit it.

### Research conclusions

Utilization of HSCT in RA cases that are refractory to the conventional line of management maintained remission to a maximum of 2 years. With the rise in the resistance to traditional therapy for RA, earlier identification of those non-responders based on clinic-serological profile and prognostic markers remains a key element to reap the maximum benefit out of this modality.

### Research perspectives

Before the inclusion of HSCT into the routine management protocol for RA, certain questions need further exploration to standardize the treatment protocol to harness maximum benefits out of the procedure.

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