Netherlands
The Journal of Medicine

Aplastic anaemia: a review

S. Sleijfer[1], P.J. Lugtenburg[2*]

Departments of [1]Internal Medicine and [2]Haematology, Erasmus Medical Centre, University Medical Centre, PO Box 2040, 3000 CA Rotterdam, the Netherlands, tel.: 31 (0)10-463 92 22, fax: 31 (0)10-463 58 14, e-mail: p.lugtenburg@erasmusmc.nl, * corresponding author

ABSTRACT

Aplastic anaemia is featured by bone marrow hypocellularity and peripheral pancytopenia and is a potentially fatal disease. In recent years, insight in its pathogenesis has increased. It appears that activated autoreactive T lymphocytes induce apoptosis of haematopoietic stem cells resulting in a hypocellular bone marrow. Nowadays, it can be treated by stem cell transplantation or immunosuppressive therapy. This review focuses on the pathophysiology and treatment of aplastic anaemia.

INTRODUCTION

Aplastic anaemia is a serious medical disorder which, when untreated, has a median survival of less than ten months[1] due to infections and haemorrhage. Fortunately, in the last decades its prognosis has improved dramatically and most patients now achieve durable responses. Aplastic anaemia is featured by hypoplasia of the bone marrow and peripheral pancytopenia (*figure 1*). The most commonly used criteria for the diagnosis aplastic anaemia are marrow cellularity of less than 25% of normal or less than 50% with haematopoietic cells representing less than 30% of the residual cells and at least two of the following peripheral blood counts: neutrophil count of less than 0.5 x 10^9/l, platelet count of less than 20 x 10^9/l, and/or anaemia with a reticulocyte count of less than 1%.[2]
Aplastic anaemia can be due to congenital (20%) or acquired causes (80%) (*table 1*). Congenital diseases leading to aplastic anaemia will not be further discussed here.

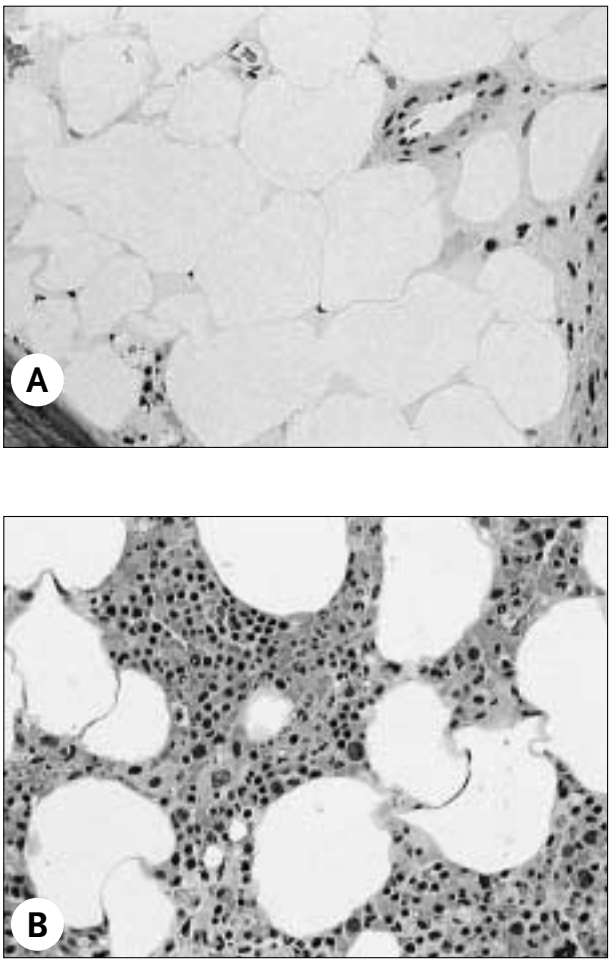

Figure 1
Bone marrow biopsy from a patient with aplastic anaemia (A) compared with a normal bone marrow (B)

Causes of acquired aplastic anaemia are very diverse, the most common being iatrogenic causes such as radiation and drugs directly cytotoxic to the bone marrow. Some haematological malignancies or infections can present as aplastic anaemia. In some cases, myelodysplastic syndrome (MDS) can occur with a hypocellular bone marrow and peripheral pancytopenia. In these cases, it is sometimes difficult to distinguish between MDS and aplastic anaemia. Distinction by cytogenetic analysis is not always possible because in about 4% of the patients with aplastic anaemia cytogenetic abnormalities are found, sometimes similar to those seen in patients suffering from MDS.[3] Furthermore, not all patients with evident morphological MDS have cytogenetic alterations. Some institutions consider patients with findings fulfilling the diagnosis of aplastic anaemia and with cytogenetic abnormalities as MDS, independent of the marrow morphology.[4]
The management of acquired aplastic anaemia due to such causes as aforementioned involves treatment of the underlying cause. This review, however, will focus on the remaining causes of acquired aplastic anaemia in which haematopoietic stem cell damage due to autoreactive T lymphocytes is the central event but in which the exact cause that elicits this reaction is largely unknown.

Table 1
A classification of aplastic anaemia

CONGENITAL	
Fanconi anaemia	
Shwachman-Diamond syndrome	
Dyskeratosis congenita	
Amegakaryocytic thrombocytopenia	
ACQUIRED	
Idiopathic	
Haematological malignancies	Hypocellular MDS
	Hairy cell leukaemia
	Acute lymphatic leukaemia
Infectious	Posthepatitis
	Parvovirus B19
	HIV
	Mycobacterial infections
	EBV
Toxic	Radiation
	Cytostatics
	Idiosyncratic
	Pregnancy
Autoimmune disorders	Eosinophilic fasciitis
	GVHD

EPIDEMIOLOGY AND AETIOLOGY

Aplastic anaemia is a rare disease with a reported incidence of approximately 2 per 1 x 10^6 annually in Europe. In Asia, it occurs three times more often with an incidence of 5 to 7 per 1 x 10^6 annually.[5]
As will be described below, autoreactive T lymphocytes are thought to play an important role in the pathogenesis of aplastic anaemia. As in other autoimmune diseases, an association with certain HLA alleles has been described in patients with aplastic anaemia. In these patients, an increased HLA-DR2 frequency of 58% is found, versus 28% in the normal population.[6]
Because prognosis of aplastic anaemia is related to the number of neutrophils, aplastic anaemia is divided into nonsevere aplastic anaemia with neutrophils above 0.5 x 10^9/l, severe aplastic anaemia with neutrophils between 0.2 and 0.5 x 10^9/l, and very severe aplastic anaemia with neutrophils lower than 0.2 x 10^9/l.[7]
The aetiology of acquired aplastic anaemia is very diverse. Aplastic anaemia usually occurs without a suggestive prior history and is labelled idiopathic. However, in some cases a clear inciting event can be identified. Many drugs and chemicals have been described as causing aplastic anaemia by a rare idiosyncratic reaction. The most well known are drugs such as chloramphenicol, but widely used medications as furosemide and allopurinol have also been associated with aplastic anaemia.[8]
Approximately 5 to 10% of aplastic anaemia occurs after an episode of hepatitis in which no known viral pathogen or a relation with drugs can be identified.[9] Patients who receive a liver transplantation for hepatic failure caused by such a seronegative fulminant hepatitis are at a high risk of developing aplastic anaemia. It occurs in about 25% of these patients.[10] It is plausible that a not yet identified infectious agent is involved. Also parvovirus B19 is associated with aplastic anaemia.[11]
Relationships with pregnancy[12] and autoimmune disorders such as eosinophilic fasciitis have also been reported. However, whatever the underlying cause, it does not seem to affect the response to treatment.[13]

PATHOGENESIS

There are several indications that aplastic anaemia is due to a stem cell dysfunction. When stem cells of patients are seeded onto irradiated normal stromal cells in vitro, a reduced number of colony-forming units (CFU) is seen. In contrast, normal CFU forming is observed after placement of normal CD34-positive cells into stromal cells of patients.[14] Therefore stromal dysfunction appears unlikely.

Furthermore, CD34-positive cells are decreased in blood and bone marrow,[15] while in the remaining stem cells an increased percentage of apoptotic cells is seen.[16]
Evidence is mounting that a T-cell-mediated reaction may be responsible for the stem cell destruction. In bone marrow of patients an increased number of activated CD8 lymphocytes are seen.[17] Moreover, T cells of patients are capable of reducing CFU forming in vitro, while depletion of these T cells restores CFU forming.[18] Furthermore, T cells of patients produce cytokines such as interferon-γ and tumour necrosis factor-α and increased expression of these cytokines has been shown in the bone marrow of patients.[19] These cytokines can suppress stem cell proliferation and induce apoptosis of stem cells.[20] The cytokine-induced apoptosis can occur directly and indirectly by the Fas-Fas-ligand system. Interferon-γ and tumour necrosis factor-α are capable of inducing Fas expression on stem cells, and increased Fas expression is found in bone marrow of patients.[21] Fas ligand, which can be found on activated T lymphocytes, can subsequently induce apoptosis of these Fas-expressing stem cells.
The important role of these cytokines is underscored by the observation that in a murine model of aplastic anaemia, pancytopenia can be ameliorated by treatment with antibodies against IFNγ.[22]
So, at present the hypothesis is that activated CD8 lymphocytes induce apoptosis of stem cells directly as well as by cytokines produced by these CD8 lymphocytes. However, the exact mechanisms inducing this immune reaction are unknown. Because there are so many diverse causes of aplastic anaemia, it can be assumed that there are also various mechanisms leading to T-cell activation. For instance, after a viral infection, molecular mimicry may be involved and in case of an idiosyncratic drug reaction, hapten forming. Recently, it was found that the P-glycoprotein function of stem cells was reduced in patients with drug-induced aplastic anaemia compared with patients with aplastic anaemia due to another cause.[23] This decreased function of P glycoprotein, which is involved in drug efflux, may lead to increased accumulation of drugs in stem cells and subsequently result in increased cytotoxicity in these cells. Therefore, patients with decreased P-glycoprotein function might be more prone to develop drug-induced aplastic anaemia.
In a subset of patients a mechanism other than immune-mediated stem cell damage may be involved. Recently, in some patients with aplastic anaemia a germ-line mutation in the gene encoding for the RNA component of telomerase has been shown.[24] This mutation results in decreased telomerase activity and subsequently shorter telomers, which may ultimately lead to reduced survival of stem cells and to aplastic anaemia.

TREATMENT

Allogeneic stem cell transplantation (allo-SCT) using bone marrow as treatment for aplastic anaemia was first applied in the early seventies. Nowadays, peripheral stem cells are being increasingly used. When successful, a fast haematological response is seen after allo-SCT with neutrophils above 0.5 x 10^9/l and platelets above 20 x 10^9/l after a median of about 15 and 20 days, respectively. However, allo-SCT can be accompanied with severe toxicity. The main mortality and morbidity is due to graft failure, drug-related toxicity, infections and the occurrence of acute and/or chronic graft-versus-host disease (GVHD). Recently the European Group for Blood and Marrow Transplantation (EBMT) retrospectively analysed the data of 2002 patients with aplastic anaemia who had received an allo-SCT between 1976 and 1998.[25] Most patients (85%) received a transplant from an HLA-identical sibling, 13% from a matched unrelated donor, and 2% from an identical twin. Graft type clearly affected survival in these three groups with 66, 37, and 91% respectively. Data on responses were not given.
Mortality was strongly associated with age. In patients treated with allo-SCT from an HLA-identical sibling between 1990 to 1998, survival rates for patients aged <16, between 16-40, and >40 years were 77, 68, and 54%, respectively. Remarkable was the improvement in time with an increase in survival from 57% up to 1990 to 76% after 1990. This improvement is mainly caused by a decline in the occurrence of acute GVHD due to more effective prophylaxis, better matching, and improved supportive care.
In patients who are not candidates for SCT, immunosuppressive therapy (IST) is employed. Mathe *et al.* reported autologous bone marrow recovery in some patients who rejected their grafts. These authors speculated that the antithymocyte globulin (ATG) used in the conditioning regimen had induced an anti-immune process.[26] Since then, several randomised studies have been carried out. Drugs studied in a randomised setting are ATG, cyclosporine A (CsA), androgens, corticosteroids, growth factors and cyclophosphamide (*table 2*). However, these trials are very difficult to compare due to differences in inclusion criteria, definitions for response, time of follow-up, and treatment regimens. Until now, the best results have been reported with the combination of ATG and CsA. Both horse and rabbit ATG are frequently used and both are licensed for treatment in the United States. Data comparing both types ATG and several doses are not available. In our centre, the combination treatment consists of horse ATG 15 mg/kg administrated daily for five days and CsA for at least three months. Initially, CsA is administered orally twice daily at 3 mg/kg. Dosing of CsA is adjusted to

Table 2

Results of trials comparing different regimens of IST for aplastic anaemia. Definitions for response rate and follow-up for survival differs between studies

AUTHOR	N	TREATMENT	RESPONSE RATE (%)	SURVIVAL (%)	REMARKS
Champlin[27]	21	ATG	52*	62	
	21	Control	0	62	
Camitta[28]	29	ATG	69*	76*	
	13	Control	23	31	
Champlin[29]	26	ATG/andr	42	55	
	27	ATG	44	50	
Doney[30]	12	mcAb	8	58	
	13	ATG	31	77	
Kaltwasser[31]	15	ATG/andr	73	87	
	15	ATG	31	43	
Frickhofen[32]	43	ATG/Mpr/CsA	65*	64	
	41	ATG/Mpr	39	58	
Gluckman[33]	48	ATG/Mpr	30	64	
	46	CsA	32	70	
Doney[34]	31	ATG/HD-Mpr/andr	48	47	
	33	ATG/LD-Mpr/andr	36	43	
Bacigalupo[35]	69	ATG/Mpr/andr	56*	71	
	65	ATG/Mpr	40	65	
Marsh[36]	54	ATG/CsA	74*	91	
	61	CsA	46	93	
Kojima[37]	35	ATG/CsA/andr/G-CSF	55	91	Study in children
	34	ATG/CsA/andr	77	93	
Tisdale[38]	15	CsA/cycloph	46	NR	Premarurely terminated; excess mortality in cyclophosphamide group
	16	ATG/CsA	75	NR	

*ATG = antithymocyte globulin, andr = androgen, mcAb = murine antihuman T cell monoclonal antibody, Mpr = methylprednisolone, CsA = cyclosporine A, HD-Mpr = high-dose methylprednisolone, LD-Mpr = low-dose methylprednisolone, cycloph = cyclophosphamide, NR = not reported. * Significant difference ($p<0.05$).*

maintain trough levels of 100 to 300 ng/ml from day 1 to 28; from day 28 target trough levels are 50 to 150 ng/ml. CsA can be tapered off when there is a good response, and if necessary, restarted in case of relapse. During administration of ATG, corticosteroids are given for attenuating ATG-induced side effects. The corticosteroids themselves probably have a minor effect in aplastic anaemia.[34]

Good responses by this combination treatment, defined as neutrophils above 1.0 x 10^9/l and transfusion independence, are obtained in 60 to 80% of the patients. These responses, however, are rather slow and usually take three to six months to occur. Furthermore the response is often not complete (normalisation of blood counts) and about 30 to 40% show a relapse after a few years. Over time, five-year survival has improved because of better supportive care. In 1981, the five-year survival was 58% compared with 75% in 1991.[39]

In case of relapse or nonresponding disease after a first course, a second course of IST can be given. This second course is successful in approximately 50% of the patients.[40] Concern for development of serum sickness by repeated courses of ATG was examined by Tichelli *et al.*[40] These authors showed that a repeated administration of horse ATG is safe and well tolerated. Serum sickness occurred earlier but not more often.[40] When disease is refractory to repeated courses of IST, an allo-SCT can be considered when the patient was not a candidate for primary treatment with SCT.

LONG-TERM EFFECTS

Because both allo-SCT and IST have rather good effects in the short term, long-term effects are important. About 10% of the patients treated with IST for aplastic anaemia develop paroxysmal nocturnal haemoglobinuria (PNH) with haemolytic anaemia.[41] This does not occur in patients treated with allo-SCT. PNH is due to a mutation in a gene encoding for a protein which is involved in the synthesis of a glycosylphosphatidylinositol anchor (GPI)

responsible for the attachment of several proteins to the cell membrane. PNH usually presents with haemolytic anaemia but in 20 to 50% of the cases of aplastic anaemia a decreased expression of GPI-anchored proteins is found suggesting a strong link between these two conditions.[42] PNH as a long-term side effect is only found in patients who initially present with aplastic anaemia combined with a decreased GPI-anchored protein expression.[42] An explanation for this increased incidence of PNH after IST could be that stem cell clones with decreased expression of GPI-anchored proteins have a growth advantage compared with normal stem cells in aplastic anaemia. Stem cells with GPI deficiency, which can also be found in normal people,[43] appear to be less prone to apoptosis than normal cells.[44] In a disorder like aplastic anaemia, in which apoptosis-induced stem cell damage is important, this phenomenon may subsequently lead to a growth advantage for these GPI-deficient cells and ultimately to PNH.

Socie *et al.*[45] compared the incidence of malignant tumours after treatment for aplastic anaemia. It was found that the number of cancers was clearly increased compared with the general population, especially the occurrence of acute leukaemia (115 times in patients treated with IST, 29 times in patients who received a transplantation). The incidence of the development of solid tumours was only significantly increased in patients who were treated with allo-SCT (5.7 times). Comparing both treatments, especially the occurrence of acute leukaemia and MDS was clearly increased in patients who were treated with IST compared with those who received allo-SCT. Altogether, this results in a cumulative ten-year incidence of all cancers of 18.8% in patients treated with IST and 3.1% in those who received an allo-SCT.[45] The strongly increased incidence of cancer in patients treated with IST is reflected in the survival curve which is still declining after a follow-up of five years, while the curve of patients treated with allo-SCT reaches a plateau after this time period.[46]

The reason for the strongly increased incidence of cancer is not exactly known. The incidence of solid cancer after transplantation is associated to the use of radiation in the conditioning regimen.[45] The strong increase of MDS in IST can be due to the fact that the initial diagnosis was not aplastic anaemia but hypocellular MDS. Another explanation could be that the remaining stem cells, not affected by the immune system, have an increased cell cycle to compensate for the damaged stem cells. The observed shortening of telomeres in peripheral leucocytes of patients is in agreement with this hypothesis.[47] The increased cell cycle results in an augmented number of mutations which may lead to either MDS or acute leukaemia. Other possible mechanisms described as being related to the increased AML/MDS incidence are multiple courses of ATG[45] and the use of G-CSF.[48]

BEST PRIMARY TREATMENT

An important remaining question is what the first-line therapy of a patient presenting with aplastic anaemia should be. Several studies comparing the efficacy of allo-SCT and IST have been performed (*table 3*). Again, these studies are difficult to compare. Most studies did not find a difference between these treatments, except for one study performed in children which showed an advantage for allo-SCT.[52] However, the number of patients studied in these trials was rather small.

Therefore, the European Blood and Marrow Transplantation Group (EBMT) retrospectively analysed data on 1765 patients with acquired aplastic anaemia.[40] Comparing both treatments, it appears that especially in younger patients up to 40 years with a strongly decreased number of neutrophils (<0.3 x 10^9/l), allo-SCT is the best treatment, while in patients older than 40 years IST gives the best results.[40] The advantage of transplantation compared with IST in younger, severely affected patients is probably due to a shorter time of improvement of blood counts which is especially favourable in those with a severe low number of neutrophils. The advantage for IST in older patients is probably caused by the increased mortality of allo-SCT in this group. However, the difference in advantage for IST in older patients decreases in time, probably

Table 3
Results of trials comparing IST with allo-SCT for the treatment of aplastic anaemia – follow-up for survival differs

		IST		ALLO-SCT	
AUTHOR	AGE (YEARS)	N	SURVIVAL (%)	N	SURVIVAL (%)
Speck[49]	All ages	32	69	18	44
Bayever[50]	<25	22	45	35	72
Halperin[51]	<18	12	25	14	79
Locasciulli[52]	<15	133	48	171	63*
Paquette[53]	Adults	146	49	55	72

IST = immunosuppressive therapy, allo-SCT = allogeneic stem cell transplantation. Significant difference (p<0.05).*

due to relapses and the increased incidence of cancer. In patients aged up to 40 years and with a moderately affected neutrophil number there is no clear difference in five-year survival in favour of either of the treatment options.[40] However, because of the increased long-term effects of IST compared with allo-SCT, the latter is to be preferred.
So, in our institute, this has accumulated in the protocol as depicted in *table 4*.

Table 4
First, second, and third-line therapy for aplastic anaemia in the Erasmus Medical Centre

NEUTROPHILS <0.2 x 10^9/l	NEUTROPHILS >0.2 x 10^9/l
Age <45 years	*Age <20 years*
1. sib-SCT	1. sib-SCT
2. IST	2. IST
3. MUD-SCT	3. MUD-SCT
Age ≥45 years:	*Age ≥20 years*
1. IST	1. IST
2. sib-SCT (<55 years)	2. sib-SCT (<55 years)
3. MUD-SCT (<50 years)	3. MUD-SCT (<50 years)

sib-SCT = allogeneic stem cell transplantation from HLA-identical sibling, IST = immunosuppressive therapy, MUD-SCT = allogeneic stem cell transplantation from matched unrelated donor.

CONCLUSION

During the last decades, insight in the pathogenesis of aplastic anaemia has increased. In parallel with this, the prognosis of this potentially fatal disorder has improved radically. It can be expected that responses to IST will probably continue to rise partly due to new drugs tested for their efficacy in aplastic anaemia, such as mycophenolate mofetil, rapamycin, and monoclonals against the interleukin-2 receptor. Also results of allo-SCT will probably improve by better supportive care, more effective GVHD prophylaxis and less toxic conditioning regimens. This improvement of treatments urges that recommendations for treating aplastic anaemia will continue to be defined.

ACKNOWLEDGEMENT

The authors wish to thank Dr. K. Lam, Department of Pathology, Erasmus Medical Centre, for providing the figures.

REFERENCES

1. Williams DM, Lynch RE, Cartwright GE. Prognostic factors in aplastic anaemia. Clin Haematol 1978;7:467-74.
2. Camitta BM, Thomas ED, Nayhan DG, et al. A prospective study of androgens and bone marrow transplantation for treatment of severe aplastic anemia. Blood 1979;53:504-14.
3. Appelbaum FR, Barrall J, Storb R, et al. Clonal cytogenetic abnormalities in patients with otherwise typical aplastic anemia. Exp Hematol 1987;15:1134-9.
4. Maciejewski JP, Risitano A, Sloand EM, Nunez O, Young NS. Distinct clinical outcomes for cytogenetic abnormalities evolving from aplastic anemia. Blood 2002;99:3129-35.
5. Issaragrisil S, Leaverton PE, Chansung K, et al. Regional patterns in the incidence of aplastic anemia in Thailand. Am J Hematol 1996;61:164-8.
6. Maciejewski JP, Follmann D, Nakamura R, et al. Increased frequency of HLA-DR2 in patients with paroxysmal nocturnal hemoglobinuria and the PNH/aplastic anemia syndrome. Blood 2002;98:3513-9.
7. Gluckman E, Devergie A, Poros A, Degoulet P. Results of immunosuppression in 170 cases of severe aplastic anaemia. Br J Haematol 1982;52:541-50.
8. Kaufman DW, Kelly JP, Levy M, Shapiro S. The drug etiology of agranulocytosis and aplastic anemia. New York: Oxford University Press, 1991.
9. Brown KE, Tisdale J, Barrett AJ, Dunbar CE, Young NS. Hepatitis-associated aplastic anemia. N Engl J Med 1997;336:1059-64.
10. Tzakis AG, Arditi M, Whitington PF, et al. Aplastic anemia complicating orthotopic liver transplantation for non-A, non-B hepatitis. N Engl J Med 1988;319:393-6.
11. Brown KE, Young NS. Parvovirus B19 in human disease. Annu Rev Med 1997;48:59-67.
12. Aitchison RG, Marsh JC, Hows JM, Russell NH, Gordon-Smith EC. Pregnancy associated aplastic anaemia: a report of 5 cases and review of current management. Br J Haematol 1989;73:541-5.
13. Bacigalupo A. Aetiology of severe aplastic anaemia and outcome after allogeneic bone marrow transplantation or immunosuppressive therapy. Eur J Haematol 1996;57:16-9.
14. Marsh JCW, Chang J, Testa NG, Hows JM, Dexter TM. In vitro assessment of marrow 'stem cell' and stromal cell function in aplastic anaemia. Br J Haematol 1991;78:258-67.
15. Maciejewski JP, Anderson S, Katevas P, Young NS. Phenotypic and functional analysis of the bone marrow progenitor cell compartment in aplastic anaemia. Br J Haematol 1994;87:227-33.
16. Philpott NJ, Scopes J, Marsh JCW, Gordon-Smith EC, Gibson FM. Increased apoptosis in aplastic anaemia bone marrow progenitor cells: possible pathophysiological significance. Exp Haematol 1995;23:1642-8.
17. Maciejewski JP, Hibbs JR, Anderson S, et al. Bone marrow and peripheral blood lymphocyte phenotype in patients with bone marrow failure. Exp Haematol 1994;22:1102-10.
18. Kagan WA, Ascensao JA, Pahwa RN, et al. Aplastic anemia: presence in human bone marrow of cells that suppress myelopoiesis. Proc Natl Acad Sci USA 1976;73:2890-4.
19. Maciejewski JP, Selleri C, Sato T, Anderson S, Young NS. Nitric oxide suppression of human hematopoiesis in vitro: contribution to inhibitory action of interferon-γ and tumor necrosis factor-α. J Clin Invest 1995;96:1085-92.

20. Selleri C, Sato T, Anderson S, Young NS, Maciejewski JP. Interferon-γ and tumor necrosis factor-α suppress both early and late stages of hematopoiesis and induce programmed cell death. J Cell Physiol 1995;165:538-46.
21. Maciejewski JP, Selleri C, Sato T, Anderson S, Young NS. Increased expression of Fas antigen on bone marrow CD34+ cells of patients with aplastic anaemia. Br J Haematol 1995;91:245-51.
22. Wolk A, Simon-Stoos K, Nami I, et al. A mouse model of immune-mediated aplastic anemia. Blood 1998;suppl 92:abstr 639.
23. Calado RT, Garcia AB, Gallo DP, et al. P-glycoprotein function is impaired in CD34+ cells from patients with aplastic anemia. Blood 2001;suppl 98:abstr 933.
24. Vulliamy T, Marrone A, Dokal I, Mason PJ. Association between aplastic anaemia and mutations in telomerase RNA. Lancet 2002;359:2168-9.
25. Bacigalupo A, Oneto R, Bruno B, et al. Current results of bone marrow transplantation in patients with acquired severe aplastic anemia. Acta Haematol 2000;103:19-25.
26. Mathe G, Amiel JL, Schwarzenberg L, et al. Bone marrow graft in man after conditioning by antilymphocytic serum. BMJ 1970;2:131-6.
27. Champlin R, Ho W, Gale RP. Antithymocyte globulin treatment in patients with aplastic anemia: a prospective randomized trial. N Engl J Med 1983;308:113-8.
28. Camitta B, O'Reilly RJ, Sensenbrenner LL, et al. Antithoracic duct lymphocyte globulin therapy of severe aplastic anemia. Blood 1983;62:883-8.
29. Champlin RE, Ho WG, Feig SA, Winston DJ, Lenarsky C, Gale RP. Do androgens enhance the response to antithymocyte globulin in patients with aplastic anemia? A prospective randomized trial. Blood 1985;66:184-8.
30. Doney K, Martin P, Storb R, Appelbaum FR. A randomized trial of antihuman thymocyte globulin versus murine monoclonal antihuman T-cell antibodies as immunosuppressive therapy for aplastic anemia. Exp Haematol 1985;13:520-4.
31. Kaltwasser JP, Dix U, Schalk KP, Vogt H. Effect of androgens on the response to antithymocyte globulin in patients with aplastic anemia. Eur J Haematol 1988;40:111-8.
32. Frickhofen N, Kaltwasser JP, Schrezenmeier H, et al. Treatment of aplastic anemia with antilymphocyte globulin and methylprednisolone with or without cyclosporin. N Engl J Med 1991;324:1297-304.
33. Gluckman E, Esperou-Bourdeau H, Baruchel A, et al. Multicenter randomized study comparing cyclosporine-A alone and antithymocyte globulin with prednisone for treatment for severe aplastic anemia. Blood 1992;79:2540-6.
34. Doney K, Pepe M, Strob R, et al. Immunosuppressive therapy for aplastic anemia: results of a prospective, randomized trail of antithymocyte globulin (ATG), methylprednisolone, and oxymetholone to ATG, very high dose methylprednisolone, and oxymetholone. Blood 1992;79:2566-71.
35. Bacigalupo A, Chaple M, Hows J, et al. Treatment of aplastic anaemia (AA) with antilymphocyte globulin (ALG) and methylprednisolone (Mpred) with or without androgens: a randomised trial from the EBMT SAA working group. Br J Haematol 1993;83:145-51.
36. Marsh J, Schrezenmeier H, Marin P, et al. Prospective randomized multicenter study comparing cyclosporin alone versus the combination of antithymocyte globulin and cyclosporin for treatment with patients with nonsevere aplastic anemia. Blood 1999;93:2191-5.
37. Kojima S, Hibi S, Kosaka Y, et al. Immunosuppressive therapy using antithymocyte globulin, cyclosporine, and danazol with or without human granulocyte colony-stimulating factor in children with acquired aplastic anemia. Blood 2000;96:2049-54.
38. Tisdale JF, Dunn DE, Geller N, et al. High-dose cyclophosphamide in severe aplastic anaemia: a randomised trial. Lancet 2000;356:1554-9.
39. Bacigalupo A, Brand R, Oneto R, et al. Treatment of acquired severe aplastic anemia: bone marrow transplantation compared with immunosuppressive therapy. Semin Hematol 2000;37:69-80.
40. Tichelli A, Passweg J, Nissen C, et al. Repeated treatment with horse anti-lymphocyte globulin for severe aplastic anaemia. Br J Haematol 1998;100:393-400.
41. Kinoshita T, Inoue N. Relationship between aplastic anemia and paroxysmal nocturnal hemoglobinuria. Int J Hematol 2002;75:117-22.
42. Dunn DE, Tanawattanacharoen P, Boccuni P, et al. Paroxysmal nocturnal hemoglobinuria in patients with bone marrow failure syndromes. Ann Intern Med 1999;131:401-8.
43. Araten DJ, Nafa K, Pakdeesuwan K, Luzatto L. Clonal populations of hematopoietic cells with paroxysmal nocturnal hemoglobinuria genotype and phenotype are present in normal individuals. Proc Natl Acad Sci USA 1999;96:5209-14.
44. Chen R, Nagarajan S, Prince GM, et al. Impaired growth and elevated fas receptor expression in PIGA(+) stem cells in primary paroxysmal nocturnal hemoglobinuria. J Clin Invest 2000;106:689-96.
45. Socie G, Henry-Amar M, Bacigalupo A, et al. Malignant tumors occurring after treatment of aplastic anemia. N Engl J Med 1993;329:1152-7.
46. Doney K, Leisenring W, Storb R, et al. Primary treatment of acquired aplastic anemia: outcomes with bone marrow transplantation and immunosuppressive therapy. Ann Intern Med 1997;126:107-15.
47. Ball SE, Gibson FM, Rizzo S, Tooze JA, Marsh JC, Gordon-Smith EC. Progressive telomere shortening in aplastic anemia. Blood 1998;91:3582-92.
48. Kojima S, Ohara A, Tsuchida M, et al. Risk factors for evolution of acquired aplastic anemia into myelodysplastic syndrome and acute myeloid leukemia after immunosuppressive therapy in children. Blood 2002;100:786-90.
49. Speck B, Gratwohl A, Nissen C, et al. Treatment of severe aplastic anaemia with antilymphocyte globulin or bone-marrow transplantation. BMJ 1981;282:860-3.
50. Bayever E, Champlin R, Ho W, et al. Comparison between bone marrow transplantation and antithymocyte globulin in treatment of young patients with severe aplastic anemia. J Pediatr 1984;105:920-5.
51. Halperin DS, Grisaru D, Freedman MH, Saunders EF. Severe acquired aplastic anemia in children: 11 year experience with bone marrow transplantation and immunosuppressive therapy. Am J Pediatr Hematol Oncol 1989;11:304-9.
52. Locasciulli A, Veer L van 't, Bacigalupo A, et al. Treatment with bone marrow transplantation or immunosuppression of childhood acquired severe aplastic anemia: a report from the EBMT SAA Working Party. Bone Marrow Transplant 1990;6:211-7.
53. Paquette RL, Tebyani N, Frane M, et al. Long-term outcome of aplastic anemia in adults treated with antithymocyte globulin: comparison with bone marrow transplantation. Blood 1995;85:283-90.